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Clark

THE STEAM ENGINE:

A TREATISE

ON STEAM ENGINES AND BOILERS.

COMPRISING THE PRINCIPLES AND PRACTICE OF THE COMBUSTION OF FUEL,
THE ECONOMICAL GENERATION OF STEAM, THE
CONSTRUCTION OF STEAM BOILERS;

AND

THE PRINCIPLES, CONSTRUCTION, AND PERFORMANCE OF STEAM ENGINES—
STATIONARY, PORTABLE, LOCOMOTIVE, AND MARINE,
EXEMPLIFIED IN ENGINES AND BOILERS OF RECENT DATE.

*ILLUSTRATED BY ABOVE 1300 FIGURES IN THE TEXT, AND A SERIES OF
FOLDING PLATES, DRAWN TO SCALE.*

BY

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THE STEAM ENGINE.

VOL. II.

SECTION IV.

THE CONSTRUCTION OF STEAM ENGINES.

Chapter I.—THE SLIDE-VALVE AND LINK-MOTIONS.

Definitions. — Regarding the ordinary three-ported valve-face of the cylinder in conjunction with the ordinary lap-valve, the width of the opening of the steam-ports for the admission or for the release of the steam at the beginning of the stroke is known as *lead*. On the steam side it is *outside lead*, or lead for the admission; on the release or exhaust side it is *inside lead*, or lead for the exhaust. When the valve is placed at half-travel over the ports, the length by which it overlaps each steam-port either internally or externally is known as *lap*. On the steam side, for admission, it is *outside lap;* on the exhaust side *inside lap*. When the terms *lap* and *lead* are employed alone, they are understood to designate outside lap and outside lead. The *advance*, or *angular advance*, of the eccentric is a term employed to denote the angle formed by the centre-line of the eccentric as at half-travel, with the position of the centre-line of the eccentric, when the piston is at the commencement of its stroke. The *advance*, or *linear advance*, of the valve is the length by which the valve has travelled beyond its middle position—as at half-travel—when the piston is at the commencement of its stroke. The linear advance is equal to the sum of the outside lap and lead, and to the sum of the inside lap and lead. *Inside clearance*, when the valve is so formed that, at half-travel, the faces of the valve do not close the steam-ports internally, is the length by which each face comes short of the inner edge of the port. The entrances to the steam-ways, three in number, are denominated *ports*. The extreme ports leading to the ends of the cylinder are the *steam-ports;* the middle port is the *exhaust port*. The partitions which separate the ports are named *bars* or *bridges*. The flat surface in which the ports take their origin, and on which the valve travels, is the *valve-face* of the cylinder. The two working surfaces of the valve are the *faces of the valve*. The *throw* of the eccentric is equal to twice the radius of eccentricity.

The ordinary slide-valve and valve-face are shown in section in the

annexed figure;—G H is the valve-face; *a, e*, are the steam-ports; *b, d*, the bars; *c* the exhaust port; A E, D F, the faces of the valve; E, F, the outside lap at each end; B the exhaust cavity of the valve. Inside lap is not here specified; but, if the faces of the valve were extended inwardly to
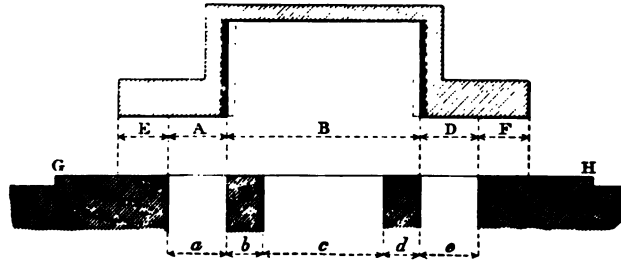
Fig. 356.—The Ordinary Slide-valve and Valve-face.

an extent, say, indicated by the dot-lines, the extension would constitute inside lap. Were the faces shortened on the inside, as shown in dark shading, the differences would be inside clearance.

The movements of the slide-valve, as driven by an eccentric fixed on the crank-shaft, in relation to those of the piston, may be exhibited diagrammatically. Take the following dimensions for illustration:—Diameter of cylinder, 15 inches; stroke of piston, 22 inches; width of steam-ports, 1¼ inches; width of exhaust port, 2½ inches; width of bars or bridges, ¾ inch; travel of valve, 4½ inches; outside lap, 1 inch; inside lap, nil; outside lead, $^5/_{16}$ inch; inside lead, 1 $^5/_{16}$ inches; angular advance, 37°; linear advance, 1 $^5/_{16}$ inches.

Four positions of the valve are shown in figs. 357, corresponding to the four quarters of a revolution of the crank. In position No. 1 the piston is at the front end of its stroke; and the eccentric, instead of being at right angles to the crank, is, as shown, considerably in advance of that position, the centre of the eccentric being 1 $^5/_{16}$ inches in advance of the vertical centre line. The valve, correspondingly, is advanced by the lap plus the lead, or 1 $^5/_{16}$ inches from its middle position. In position No. 4, accordingly, in which the crank has described only a quarter of a revolution, the eccentric has not only completed its throw, but is by as much as the angular advance, on its way on the return throw. The valve, therefore, has reached the end of its path, or has given "full port" to the steam, some time before even the first half of the throw of the crank has been completed, and is already returning to close the port. In position No. 7, in which the crank is at the commencement of its outward throw, the valve has not only closed the outer steam-port; it has also admitted steam for the outward stroke, and released the steam used in the inward stroke of the piston. All this has been done some time before the end of the inward stroke. When the position No. 10 is attained, the eccentric has completed its retrograde movement, and, consequently, that of the valve, and has recommenced its outward throw in the direction in which it set out from position No. 1.

Those positions of the valve for the cardinal positions of the crank, with eight intermediate positions—12 positions in all—are plotted in fig. 358, page 4. For the construction of this diagram, draw A B, equal to the length of the stroke of the piston, by any convenient scale of parts, and bisect it at C, on which point as a centre describe the circle A B to

No. 1

No 4.

No. 7.

No. 10.
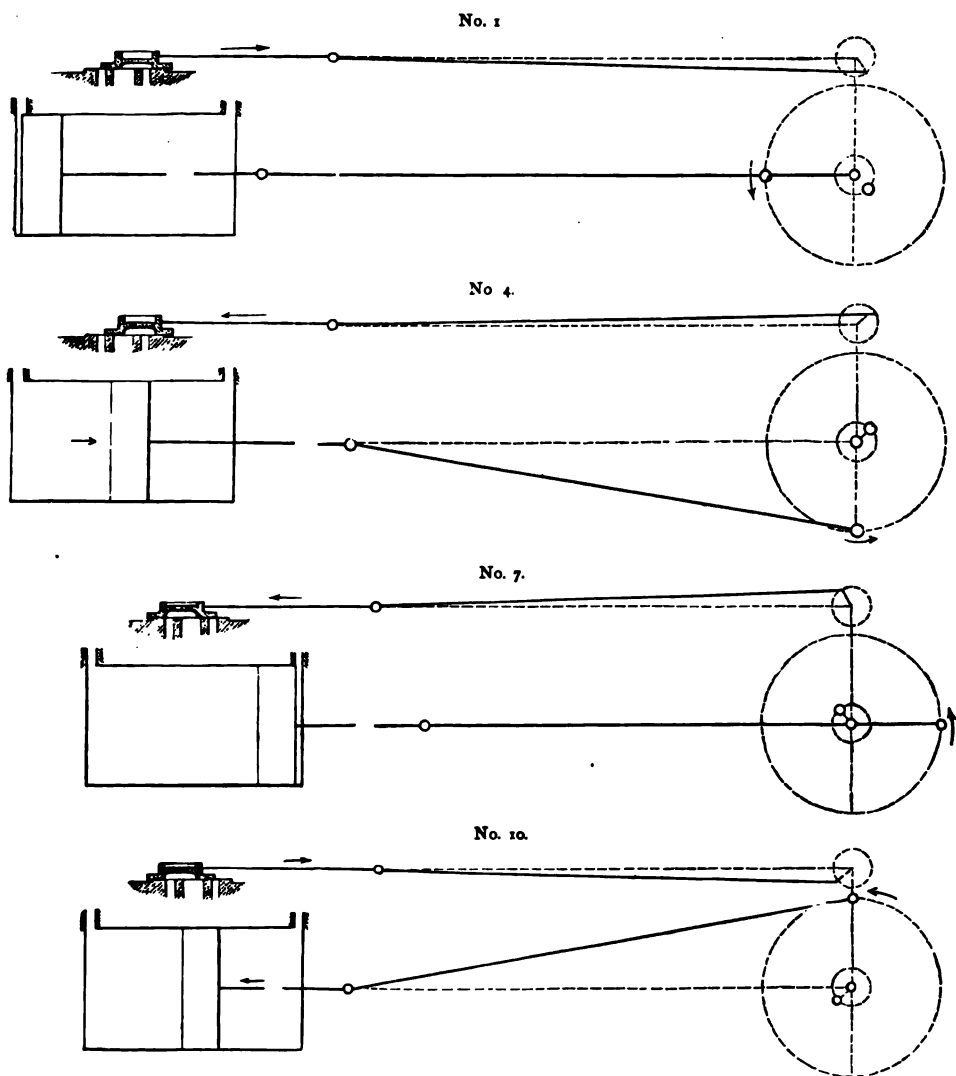
Figs. 357.—The Ordinary Slide-valve in Four Positions.

represent the path of the crank-pin; and on the same centre describe a circle, with the radius of the eccentric, to represent the path of the centre of the eccentric. Through C draw the perpendicular D E, and construct a square on the greater circle. Let the side of the square, H I, be the valve-face; set off on each side of the centre-line A B, the widths

of the ports and bars, and draw the corresponding parallels, *a, b, c, d, e, f,* across the diagram.   As the motion of the valve is the counterpart of the longitudinal movement of the eccentric, the position of the valve is directly determined by the position of the centre of the eccentric—the obliquity of the connecting-rod and the eccentric-rod being neglected.   Whilst the horizontal movement of the eccentric is reckoned in the direction of A B, right or left of the vertical D E, that of the valve is reckoned, for convenience, in the direction of D E, parallel to the valve-face H I, above or below
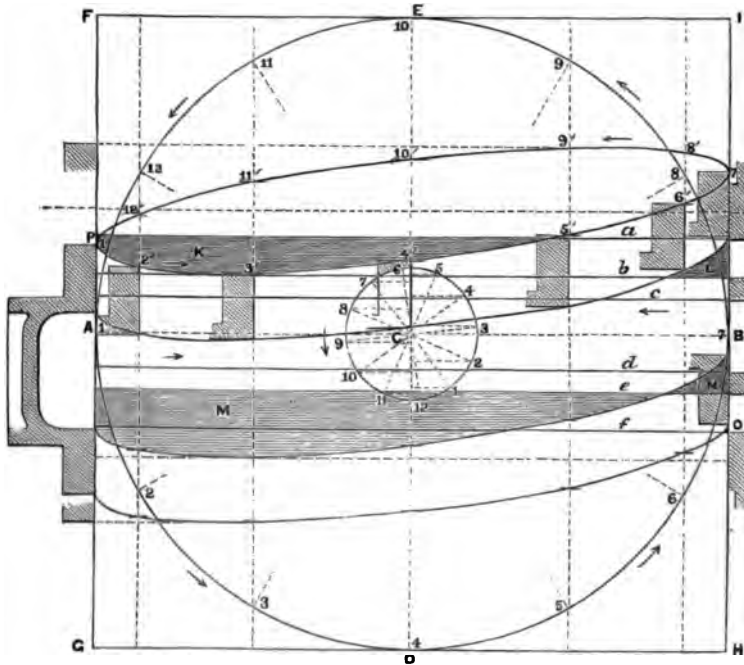
Fig. 358.—General Diagram of the Motion of the Ordinary Slide-valve.

the centre-line A B.   The middle position of the valve is defined by two dot-lines across the figure, parallel to A B.   These lines represent the total length of the valve, and they overlie the outer lines *a* and *f* of the steam-ports, by as much as 1 inch, the lap.   For the first position of the valve, it is placed at $1\frac{5}{16}$ inches, the linear advance, from its middle position, as measured on the perpendicular drawn from position No. 1, in the circular path of the eccentric to the vertical centre-line E D.   Divide both circles into 12 parts, as numbered in succession from point No. 1, and draw radial lines through the points of division, representing the successive simultaneous positions of the crank and the eccentric.   The transverse lines drawn through the points of division on the larger circle parallel to E D represent the corresponding positions of the piston during the inward and outward strokes; whilst the perpendiculars drawn to the datum-line E D from the points of division in the smaller circle, measure the simultaneous

longitudinal movements of the eccentric, or the distances of the valve-edges above or below their middle positions. These are duly set off on the ordinate lines parallel to E D, and it is observable that these positions range in elliptic curves which are inscribed on the diagram, and which embrace not only the 12 positions of the valve already determined, but also every intermediate position.

To render the action of the valve the more apparent, with respect to the distribution of the steam, the motion of the steam side during the admission of steam for the in-stroke is defined by dark shading, K, between the line *a*, for the edge of the steam-port and the elliptic curve. The movement of the valve for exhausting the steam towards the end of the in-stroke, is distinguished by the shaded space L. At the other side of the piston, during the same stroke, the other steam-port is wide open for exhaust, as indicated by the shading M, and is only closed towards the end of the stroke, at the point where the curve crosses the line *e*. The wasted steam is, from this point, locked up in the cylinder, and is subjected to compression by the advancing piston, until the port is opened for admission; and the triangular shaded space N represents the period of compression. Just before the completion of the in-stroke, when the piston has about $5/_{32}$ inch yet to describe, the other steam side of the valve opens the port for the admission of steam, preparatory to the commencement of the out-stroke, at a point represented by the intersection of the elliptic curve with the line *f*. The very small period of admission against the piston is distinguished by the small triangular shaded space O, at the termination of which the port is open $5/_{16}$ inch, being the lead for the commencement of the out-stroke. A similar triangular spot, showing the preparatory opening for the in-stroke, is observable at the opposite corner of the diagram, P.

As the motion-curves of the four edges of the valve are identical in form, one curve may be employed to represent them all, by assuming a common axis. Whilst the diagram may thus be concentrated, the distribution is indicated equally well. For example, draw the datum-line A B,
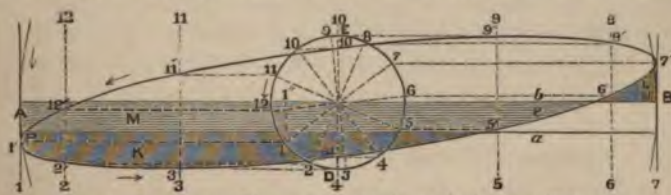
Fig. 359.—Concentrated Diagram of the Motion of the Ordinary Slide-valve.

fig. 359, for the length of stroke; bisect it, and draw the vertical line D E through the centre; on this centre draw circles, as before, for the paths of the crank-pin and eccentric. Divide the crank-circle, as before, into 12 equal segments. Adopt, for simplicity, the central datum-line A B, from which the longitudinal motion of the eccentric is to be measured, instead of the vertical line E D, as in the previous diagram. Set off on the smaller circle the point 1, of which the perpendicular distance 1, 1″, from the

datum-line, is equal to the linear advance; and, starting from this point, divide the circle into 12 equal segments; and, from the points of division severally, draw lines parallel to the datum-line to meet the transverse lines from the crank-circle, correspondingly numbered. The points of inter-section, 1′, 2′, 3′, &c., so found, are points of the motion-curve, which may thence be completed. The central datum-line A B, represents the lines *b* and *e*, fig. 358, for exhaust and compression; and to represent the working edges of the steam-ports, *a* and *f*, fig. 358, for admission and cut-off, draw a steam-line, *a*, fig. 359, 1 inch apart from, and parallel to the datum-line. Thus, the period of admission during the in-stroke is represented, as in fig. 358, by the area K inclosed by the steam-line, and the release of the steam so admitted is expressed by the area L, bounded by the datum-line, towards the end of the stroke. The letters of reference in fig. 359, corre-spond with those in fig. 358.

ZEUNER'S VALVE-DIAGRAM.

The form of diagram, fig. 360, introduced and first published by Professor Zeuner, for defining the movements of the slide-valve and the points of the
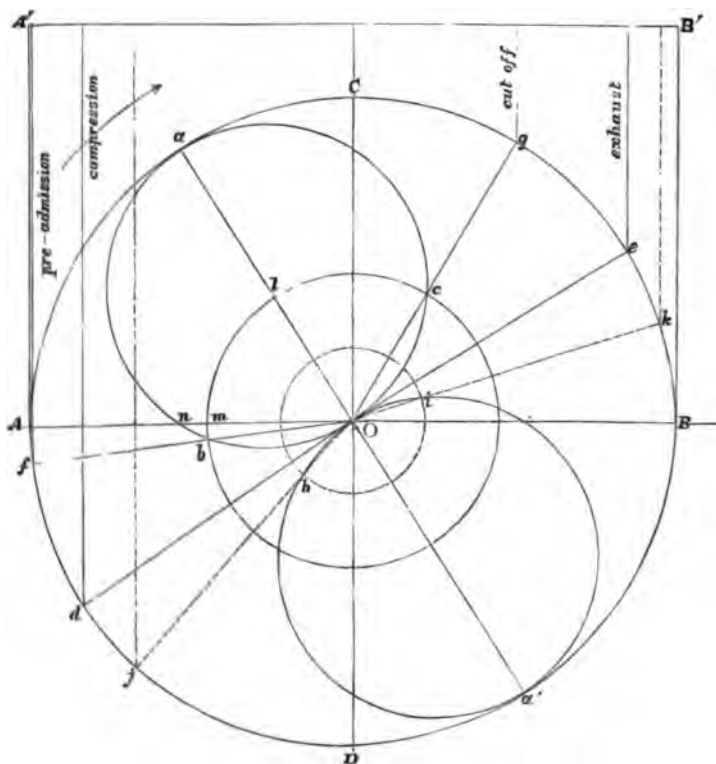
Fig. 360.—Zeuner's Diagram of the Motion of the Ordinary Slide-valve.

distribution of steam is simple and exact. It is in general use for this purpose. Draw two lines, AB and CD, at right angles to each other, inter-

secting at O; and, with the radius AO equal to half the travel of the valve, describe the circle A B, which may be taken to represent the path of the crank-pin. Set off the diameter aOa', at the angle aOC equal to the angular advance of the eccentric, and on the radii aO, Oa', describe the circles aO, Oa'. On the centre O, with the radius Ob, equal to the outside lap of the valve, describe a circle cutting the circle aO at b and c; and through these, the points of intersection of the circles, draw the radii Of, and Og. Draw the diameter dOe at right angles to the diameter aOa'. In the diagram thus constructed, all the points of the distribution are determined, for cases of no inside lap. Taking A B for the stroke of the piston, the point f is the position of the crank-pin when the valve opens for lead at A, the beginning of the stroke; g is the position when the steam is cut off; e is the position when the valve is opened for exhaust; and d is the position when the exhaust side of the valve is closed for compression.

For cases of inside lap on the valve, describe the circle hi, with a radius equal to the inside lap, cutting the circle Oa' at h and i; and through these points draw the radii Oj, Ok. Then the point k in the outer circle is the position of the crank-pin when the exhaust is opened, and the point j is the position when it is closed for compression.

To show directly the positions of the points of distribution in the stroke of the piston, draw a parallel A′B′ to the base-line A B, and draw ordinates to it from the several points of the distribution in the circle A B. The intersections of these ordinates with the projected line A′B′ give the points of the distribution for the stroke of the piston. They are to be corrected, of course, for the obliquity of the connecting-rod.

The lunar segment acb represents the amplitude of the opening of the steam-port; the opening for any position of the crank, as aO, being measured by the portion of the radius al cut off by the lap-circle blc. The segment mn shows the lead of the valve, or the length open at the beginning of the stroke.

In the diagram, the dimensions assumed for the valve, are,—travel $4\frac{1}{2}$ inches, lap 1 inch, lead $5/16$ inch, as already employed in the construction of the elliptical diagrams, figs. 358 and 359, pages 4 and 5. The correspondence of the two kinds of diagrams can be readily traced.

PROPORTIONS OF SLIDE-VALVES.

The distribution of steam by means of the slide-valve is regulated by varying the three elements,—lap, lead, and travel of valve; and their influence may be simply exemplified by means of the motion-curve or condensed diagram already explained, fig. 359. In curve No. 1 of the annexed fig. 361, is repeated the motion of the valve, having $4\frac{1}{2}$ inches of travel, 1 inch of lap, and $5/16$ inch of lead, represented in fig. 359. According to the scale of 100 parts of the stroke, appended to the figure, the steam is cut off at 73.5 per cent, and is exhausted at 91 per cent of the stroke. If the travel, lap, and lead be increased in the same ratio—say, trebled—the travel would be $13\frac{1}{2}$ inches, the lap 3 inches, and the lead $15/16$ inch.

With these data the curve No. 2, fig. 361, has been constructed; and it appears that the distribution is unaltered. It is to be inferred that if the

Exhaust line.

Steam line No. 1.

Steam line No. 2.
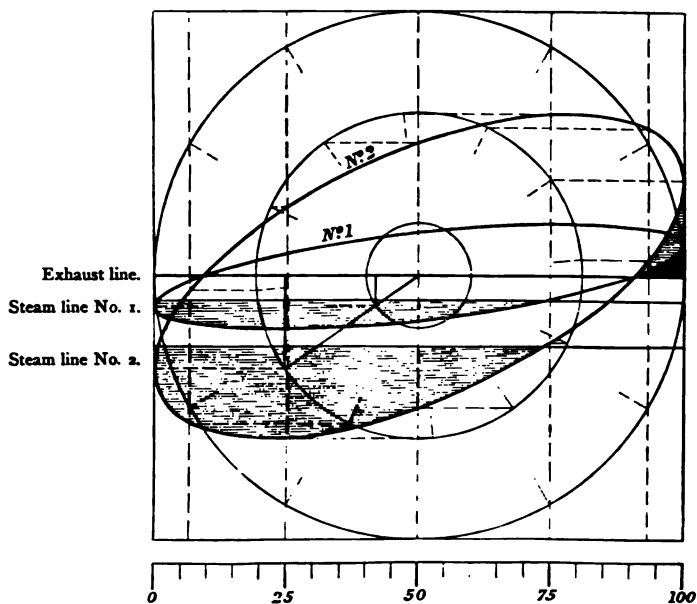
Fig. 361.—Motion-curves of an Ordinary Slide-valve, on Different Scales.

Travel, 5¼ inches.
— 4½ —
— 3¾ —
— 3 —
— 2⅝ —

Exhaust line.

Steam line.
Lin. adv. 1 5/16 in.
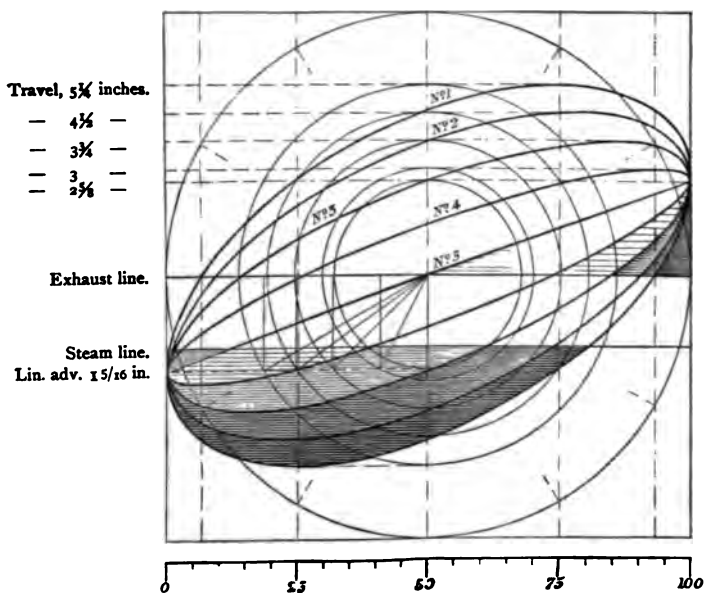
Fig. 362.—Diagram to show the Influence of Varying Travel on the Motion of an Ordinary Slide-valve.

three elements, lap, lead, and travel, be increased or diminished in the same proportions, the percentage of admission continues unaltered, and likewise also the points of release, compression, and pre-admission of steam.

The influence of the values of travel, lap, and lead, taken separately, may most readily be appreciated by means of distinct diagrams. The
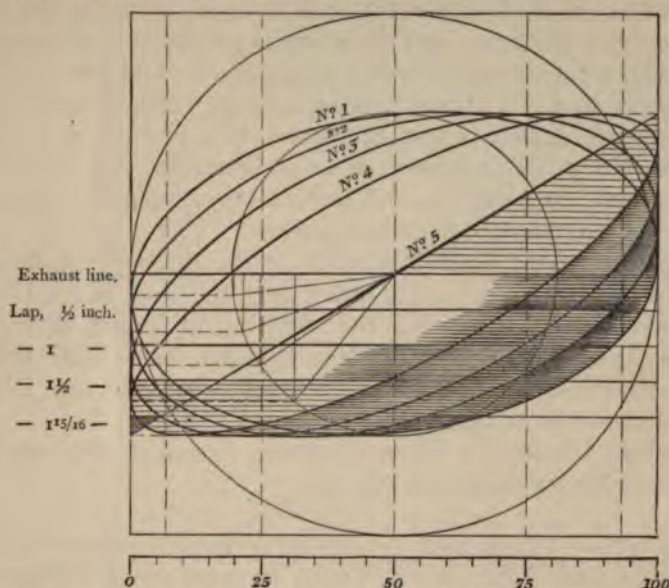
Fig. 363.—Diagram showing the Influence of Varying Lap on the Motion of an Ordinary Slide-valve.
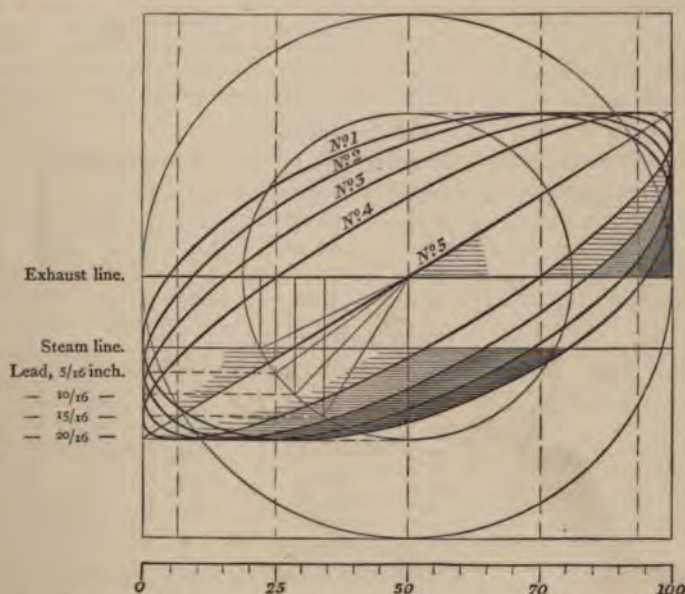
Fig. 364.—Diagram to show the Influence of Varying Lead on the Motion of an Ordinary Slide-valve.

three figures, 362, 363, and 364, comprise each a series of motion-curves formed from various travels, various laps, and various leads, respectively. In fig. 362, with a constant lap of 1 inch, and 5/16 inch of lead. the travel is

varied from 4½ inches to 2⅝ inches, which is just twice the linear advance, and for which the motion-curve, No. 5, becomes a straight line. The period of admission is reduced as the travel is reduced, until for 2⅝ inches of travel it is only 12 per cent; and the steam is released at half-stroke.

In fig. 363, with a constant travel of 4½ inches, and lead 5/16 inch, the lap is increased to 1 15/16 inches, making, with 5/16 inch of lead, 2¼ inches of linear advance, which is half the travel, and reduces the curve to a straight line, No. 5. The special effect of increasing lap is, like that of shortening travel, to compress the motion-curve, shorten the period of admission, and lengthen the period of exhaust.

Varying lead is the least influential of the three elements. With a constant lap of 1 inch, and a 4½-inch travel, the lead is, for illustration, fig. 364, increased till it reaches the extravagant length of 1¼ inches, making with the lap 2¼ inches of linear advance, or half the travel; and even then, when the motion-curve becomes a straight line, No. 5, the period of admission is as much as 28 per cent.

The leading features of these diagrams, figs. 362, 363, and 364, are stated in the following table, No. 164:—

Table No. 164.—Distribution of Steam in the Cylinder with varying Travel, Lap, and Lead of the Valve, in parts of the Stroke of the Piston.

		Cut-off.	Exhaust and Compression.	Pre-admission.	Linear Advance.	Angular Advance.
		per cent.	per cent.	per cent.	inches.	degrees.
First Series.						
Fig. 362. Travel. Travel decreasing; lap, 1 inch; lead, five-sixteenths.						
No. 1......5¼ inches......		81.5	93.5	.4	1 5/16	30°
No. 2......4½ ,, ...		73.5	91.0	.62	1 5/16	35°
No. 3......3¾ ,, ...		60.0	86.0	1.1	1 5/16	44°
No. 4......3 ,, ...		39.0	73.5	2.6	1 5/16	62°
No. 5......2⅝ ,, ...		12.0	50.0	12.25	1 5/16	90°
Second Series.						
Fig. 363. Lap. Lap increasing; travel, 4½ inches; lead, five-sixteenths.						
No. 1...... 0 inch.........		99.25	99.25	.75	5/16	7°
No. 2...... ½ ,, ...		91.5	97.0	.90	13/16	20°
No. 3......1 ,, ...		73.5	91.0	1.00	1 5/16	35°
No. 4......1½ ,, ...		49.0	81.0	1.12	1 13/16	51°
No. 5......1 15/16 ,, ...		6.5	50.0	6.50	2¼	90°
Third Series.						
Fig. 364. Lead. Lead increasing; travel, 4½ inches; lap, 1 inch.						
No. 1...... 0 inch.........		80.5	95	0	1	26°
No. 2...... 5/16 ,, ...		73.5	91	.62	1 5/16	35°
No. 3......10/16 ,, ...		64.0	84	3.0	1 5/8	46°
No. 4......15/16 ,, ...		53.5	75	8.5	1 15/16	60°
No. 5......20/16 ,, ...		28.0	50	28.0	2¼	90°

The values of the periods of expansion for varying periods of admission, are measures of the comparative efficiency of the three modes of procedure for varying the period of admission. With varying travel, the periods of admission and expansion are as follows:—

	Period of Admission.			Period of Expansion.	
No. 1............	81.5	per cent	....	12	per cent.
No. 2............	73.5	,,	....	17.5	,,
No. 3............	62.0	,,	....	23	,,
No. 4............	39.0	,,	....	34.5	,,

Lay down a base-line, A B, fig. 365, as the length of the stroke. From A set off 81.5 per cent on the base-line, the period of admission for
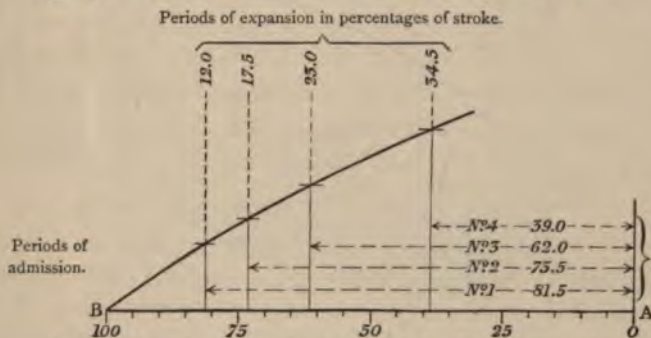
Fig. 365.—Expansion-curve for Varying Travel of an Ordinary Slide-valve.

No. 1, and draw an ordinate equal in length to 12 per cent, the period of expansion. Set off in the same way, from the point A, the periods of admission for Nos. 2, 3, and 4, with their respective ordinates of expansion. The curve joining the extremities of the ordinates passes also through the point B. Find, in the same manner, curves of expansion-periods for varying lap and varying lead. The three curves are placed together on the same base-line, in fig. 366, for comparison. The ordinate for 73.5 per cent of admission is common to the three curves. It appears that varying lap is the most efficient mode of working with variable expansion. It is slightly better for expansive working than varying travel; and its

Fig. 366.—Expansion-curves for Varying Lap, Lead, and Travel of an Ordinary Slide-valve.

periods of pre-admission are shorter. Variation by lead is obviously a poor mode of working; the expansion-period soon reaches its maximum.

Of the two modes of varying expansion—by lap and by travel—the latter involves mechanism of a simpler character than that which is required

by the former.   Variation by travel, with constant lap, appears generally to
be the most eligible means of varying expansion.

The influence of inside lap and inside clearance is illustrated by fig. 367.
The addition of inside lap defers the point of release, and, consequently,
like outside lap, prolongs the period of expansion.   But it hastens the
compression.   Inside clearance operates reversely: it hastens the release,
shortens the expansion, and delays the compression.   In fig. 367, for
$4\frac{1}{2}$ inches of travel, 1 inch of outside lap, and $5/16$ inch lead, $\frac{1}{2}$ inch of lap is
added inside.   The exhaust parallel is $\frac{1}{2}$ inch above the datum-line, and
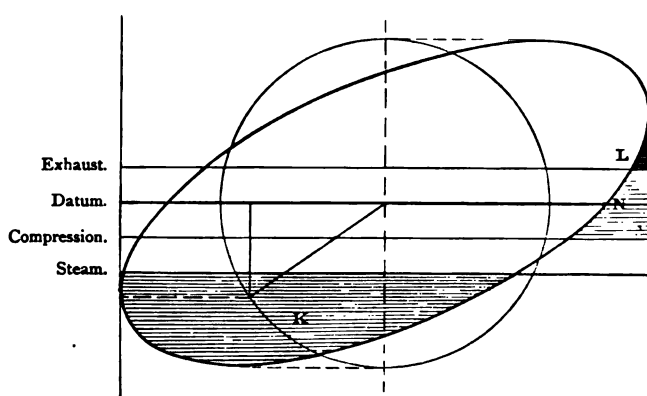
Fig. 367.—Diagram showing Effects of Inside Lap and Inside Clearance on the Motion
of an Ordinary Slide-valve.

the compression parallel $\frac{1}{2}$ inch below it.   The steam surface K remains
unaffected by the addition of inside lap; the exhaust area L is shorter than
in the original diagram, fig. 358; the period of compression N is fully as
much greater than it was before as the period of release is less.   An inside
clearance of $\frac{1}{2}$ inch, on the contrary, would exactly reverse the periods of
exhaust and compression: L representing compression, and N release.

Experience shows that neither inside lap nor inside lead are required
for the ordinary slide-valve.

LINK-MOTIONS.

Link-motions are designed for two purposes: to supply a simple means
of reversing an engine, and a means of varying the periods of admission
and expansion by varying the travel of the valve.   A link-motion is a
combination of two eccentrics—forward and backward eccentrics—and
their rods, with a link connecting the extremities of the rods, so that, by
means of the link, the valve-rod spindle may be placed in direct connection
with either eccentric; or so that it may be partially controlled by both eccen-
trics, and receive in this case a movement compounded of the motions of
the two eccentrics.   Link-motions are of three classes.   Assuming, for
explanation, that the motion is arranged horizontally, the link is, in the
first class, suspended directly from a fixed point, as a stationary link, with
a shifting valve-rod, known as the Gooch link: in the second class, the

link is movable or may be shifted vertically, carrying with it, of course, the eccentric-rods which are directly connected to it, known as the Stephenson link; in the third class, both the valve-rod and the link are movable, or may be shifted vertically, one upwards and the other downwards, known as the Allan link, or the straight link. The link is of various forms, some of which are shown in figs. 368, 369, and 370. The box link, fig. 368, is formed in two halves or sides bolted together at the extremities, inclosing a rectangular recess for the reception of the sliding block, as shown in section. The eccentric-rods are attached to the extreme stud-pins, on the outside of the link, and thus a clear way is obtained for the block or die from one end of the link to the other. The block may even be placed coincident with either stud-pin. In the two forms of open link, figs. 369 and 370, the

Fig. 368.—Box Link.

Fig. 369.—Open Link, coupled behind.
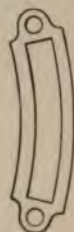
Fig. 370.—Open Link, coupled on the centre line.

links are simpler than the box link; but the form, fig. 370, with end connections for the eccentric-rods, does not admit of the block being placed coincident with the eccentric-rod ends. The range being thus limited, the block cannot receive and transmit the full extent of the throw of the eccentric—a feature in which the box link and the back-connected link, fig. 369, have the advantage.[1]

THE STATIONARY LINK.

Our normal link-motion, illustrated by fig. 371, consists of a stationary box link, sustained from below, with a pair of movable sliding blocks, considered as one in the following discussion, hung on the end of the valve-rod link. The following definitions may be premised with regard to a link-motion arranged horizontally.

The forward and backward eccentrics a, a', are fixed on the crank-shaft. They are known briefly as the *fore eccentric a*, and the *back eccentric a'*. They may be represented by the radius of throw simply. The eccentric-rods b, b', are distinguished as the *fore eccentric-rod b*, and the *back eccentric-rod b'*. The "link" c is known simply as *the link*. The link d, by which the "link" is sustained over the transverse shaft f, is the *sustaining link*. When the shaft f is above the "link," the link d is called the *suspending link*. The link e, proceeding from the valve-rod g to the "link," is the *radius link* or *valve-rod link*. The *reversing lever h* is keyed on the *reversing shaft i*. The link k is the *reversing link*, connecting the valve-rod link with the reversing lever, and sustaining the valve-rod link in position.

[1] The whole subject of link-motions has been exhaustively analysed by the author in *Railway Machinery*, 1855; Blackie & Son.
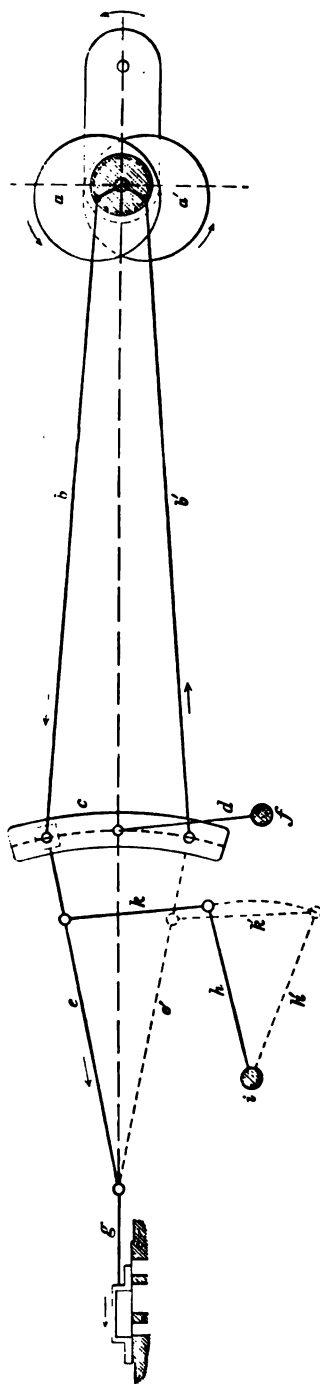
Fig. 371.—Stationary Link-motion, Normal (No. 1). In Full-gear Forward, for the beginning of the Back Stroke.

In the figure the valve-rod link is shown in *full-gear forward*, with the fore eccentric-rod. The dot-lines *e'*, *k'*, and *h'* indicate the position of the *reversing* mechanism for *full-gear backward*. The system of eccentrics, rods, and links, through which the valve receives its motion from the axle, is known as the *link-motion*, *valve-motion*, or *valve-gear*. The last includes also the reversing mechanism. The *front stroke*, *in stroke*, or *inward stroke* of the piston is that which is described from the front end, or outer end, of the cylinder, towards the crank-shaft. The *back stroke*, *out stroke*, or *outward stroke* is described reversely. The expressions *front stroke* and *back stroke* are most commonly employed with regard to locomotives.

The principal dimensions of the mechanism, fig. 371, with which the distribution of the steam is concerned, are as follows:—Lap of valve, 1 inch; lead, 5/16 inch; throw of each eccentric, 4½ inches; length of each eccentric-rod, 54 inches; length of the link measured directly between the ends of the eccentric-rods, 12 inches; length of the sustaining link, 12 inches; length of the valve-rod link, 30 inches; length of reversing link, 12 inches, connected at 7 inches from the centre of the sliding block; length of the reversing lever, 15 inches.

Variable cut-off and variable expansion are effected by varying the travel of the valve. The variation of travel is effected by varying the elevation of the valve-rod link and block in the link. When the block is at the top or the bottom of the link it receives its maximum travel; and in proportion as it is moved towards the centre or mid-length of the link,—the point of suspension,—the travel is reduced, the cut-off takes place earlier in the stroke of the piston, and the period of expansion is augmented. The shortest horizontal range of the link takes place at the centre of its length, and it is equal

to twice the linear advance—that is, twice
the lap plus twice the lead. The lead is
constant for all degrees of admission and ex-
pansion; and this condition is simply met
by forming the link, as a segment of a
circle, to the radius of the valve-rod link.
The eccentrics have equal throws and equal
linear advances, the rods are equal, and the
link is equally divided by the point of sus-
pension, which is in the horizontal centre-
line. The system is symmetrical on the
centre-line; and therefore, if the link be
formed circularly to the radius of the valve-
rod link, it follows that the entire link may
be swept from end to end by the block, while
the valve remains at rest, on a dead centre,
with unaltered lead.

Suppose the crank and eccentrics to have
made a half revolution, as in fig. 372. The
system is symmetrical as before; but the
eccentric-rods being crossed are more oblique
in position, and the link has been removed
from its first position by as much, at least, as
twice the linear advance of the eccentrics—
in fact a little more than this, by as much as
the eccentric-rods, being more oblique to the
centre-line, are virtually shortened. The
link occupies a new position parallel to its
first position, and the new position of the
valve is such as to give lead equal to that
given for the out stroke. The space through
which the valve is shifted from its first posi-
tion is shown in the figure 372, and is equal
to the space through which the link is shifted.
It is, in short, twice the linear advance of the
valve; and as the horizontal removal of the
link slightly exceeds the double of the linear
advance of the eccentrics, the linear advance
of the valve must also be something greater
than that of the eccentrics.

To place the eccentrics, they must be so
placed as to yield the necessary linear advance
of the valve, or the double of it between the
positions of the link at the two ends of the
stroke. Let A B, fig. 373, be the centre-line,
and *o* the centre of the driving axle. Through *o* draw the vertical C D, and
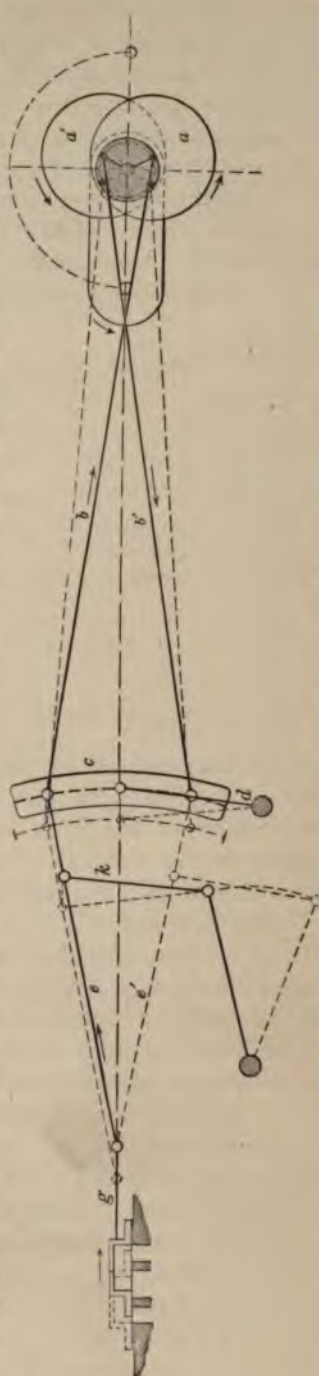
Fig. 372.—Stationary Link-motion (No. 1). In Full-gear Forward, for the beginning of the Front Stroke.

describe the circle a, $4\frac{1}{2}$ inches in diameter, for the path of the eccentrics. Draw the parallels m, n, 12 inches apart, equally distant from the centre-line,—the centres of the link being 12 inches apart. On the centre o, with the length of the eccentric-rod as radius, which in this case is assumed for convenience at 27 inches, or six times the throw of the eccentrics, cut the line m at t, and draw to. Set off or and os, each equal to the linear advance of the valve,—$1\,5/16$ inches,—and draw the perpendiculars ra, sa'', to meet the circle. Draw the diameter aa'', then oa and oa'' are the positions of the fore eccentric for the lead of the in and out strokes respectively. From a and a'' as centres, with the length of the rod, cut the line
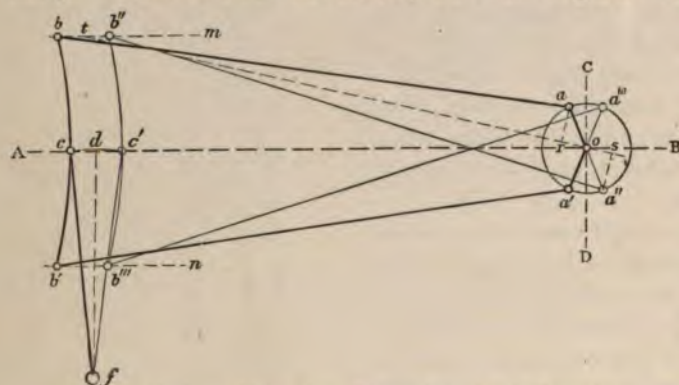
Fig. 373.—Stationary Link-motion. Diagram for setting the Eccentrics.

m at b and b'', and join ab and $a''b''$. These are the positions of the fore eccentric-rod for the out and in strokes; and the space bb'', equal to rs, measures twice the linear advance of the valve. This construction is empirical, but it is in ordinary cases satisfactory, and the points are easily adjusted, if the interval bb'' be not exactly equal to twice the linear advance. The position of the back eccentric at a' and a''' is found by drawing parallels to the vertical C D, through the points a and a''. The lower centres of the link, at b' and b''', are found similarly to the centres at b and b''. Draw bcb' and $b''cb'''$ for the relative positions of the link. From c and c' as centres, with the length of the sustaining link as radius, find the point of intersection f, the position of the fulcrum, over which the link will vibrate equally on both sides of the vertical fd.

The linear advance of the eccentrics, in fig. 373, that is, the perpendicular distance of their revolving centres from the vertical C D, does not exceed $\frac{7}{8}$ inch, which is nevertheless sufficient, aided by the obliquity of the rods, to cause an advance of $1\,5/16$ inches at the link. Applying the same method to find the set of the eccentrics for the 54-inch rods of the valve-motion already illustrated, figs. 371 and 372, the advance of the eccentrics is exactly 1.075 inches, or over $1\,1/16$ inches, for $1\,5/16$ inches of advance of valve.

The open forms of link already described require a like process for the setting of the eccentrics.

To follow the movements of the link, figs. 371, 372, for one revolution of the crank, adopting the values already stated: $4\frac{1}{2}$ inches of travel, 1 inch of lap, and $5/16$ inch of lead. Let the circle of revolution be divided into

12 equal segments, commencing at the dead point, numbered 1 to 12. Let the circular path of each eccentric be likewise divided into 12 equal segments, correspondingly numbered 1 to 12. Find the successive positions of the link, by model or by diagram, and plot them as shown in fig. 374. From this diagram it appears that the link is upright in the 1st and 7th positions, when the crank is at the dead centres, and it attains its greatest
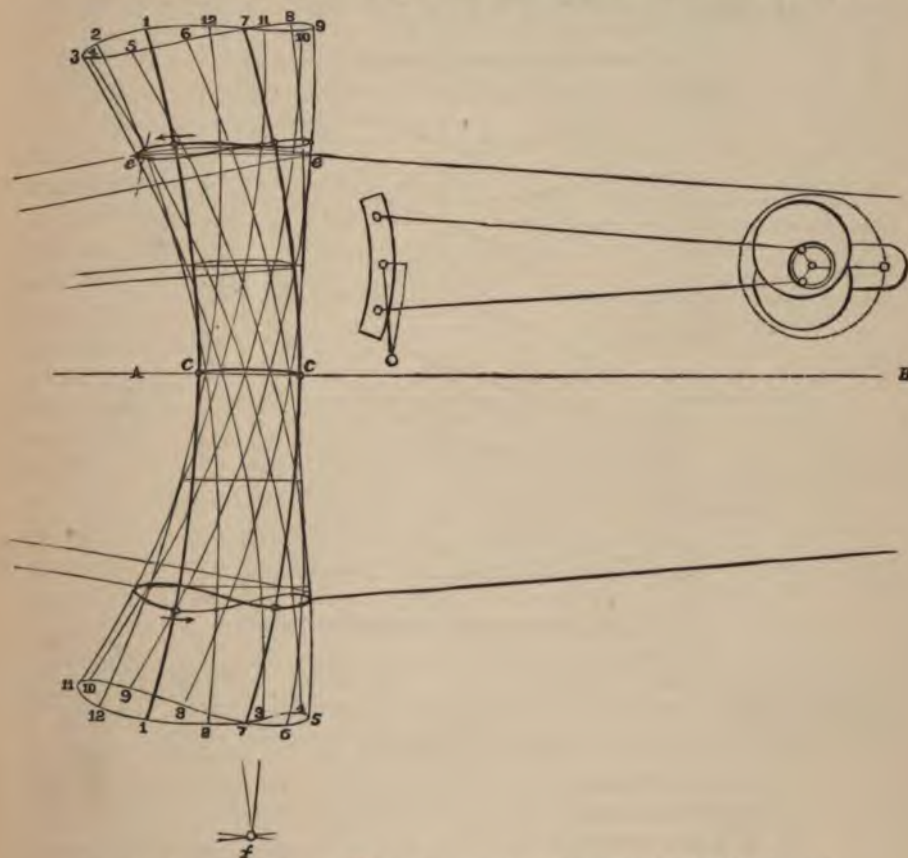
Fig. 374.—Stationary Link-motion (No. 1). Diagram of the Positions of the Link for One Revolution of the Crank-shaft.

inclination in the 4th and 10th positions, when the crank is at half-stroke, on the upper and lower centres. The block of the radius-link vibrates in a circular arc, while engaged with the link, and that arc has only to be projected upon the group of positions of the link, to determine the successive positions of the block, and thence the positions and the travel of the slide-valve. It is shown that the traverse of the link, which gives the travel of the valve, is a minimum on the centre-line AB, where it is, in fact, expressed by the distance apart of the two positions of the link on the two dead centres, which is equal, as before explained, to twice the linear advance of the valve. The traverse of the link, and the corresponding

travel of the valve, increases as the block is shifted from the position of "mid-gear," on the centre-line, towards "full-gear forward," in the latitude of the fore eccentric-rod end, or towards "full-gear backward," at the back eccentric-rod end.   At these extreme points the traverse and travel are equal to 4½ inches.

The movements of the valve may be plotted into motion-curves, like those for the single eccentric. They are thus shown in fig. 375, for mid-
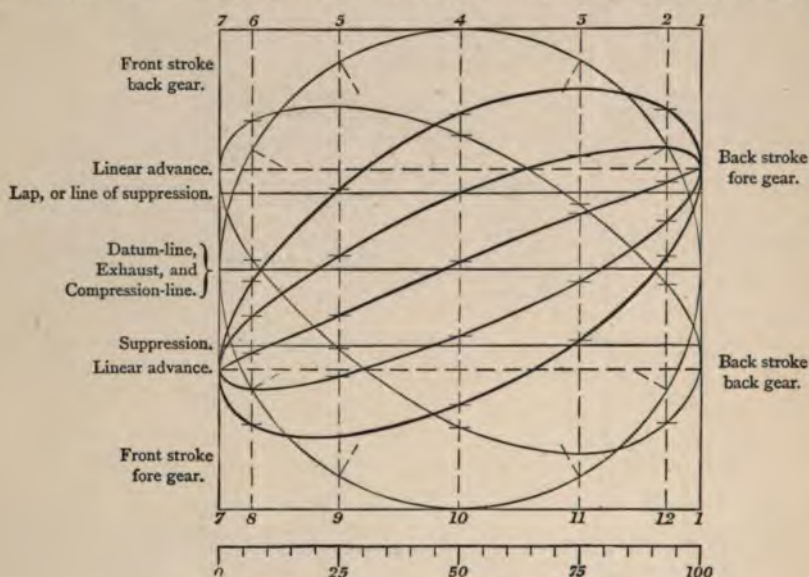
Fig. 375.—Motion-curves for Stationary Link No. 1.

gear forward, full-gear forward, and "half-gear" forward, or midway between mid-gear and full-gear; also for full-gear backward. The travels of the valve for these four positions of the gear are as follows:—

Full-gear forward................................. 4½ inches.
Half-gear forward................................ 3⅛ ,,
Mid-gear forward................................. 2⅝ ,,
Full-gear backward............................... 4½ ,,

For comparison, take the link No. 2, fig. 369, sustained by the middle, as in fig. 376, and coupled behind to the rods, at centres 12 inches apart, and 3 inches distant from the centre-line of the link; also the link No. 3, fig. 377, sustained at a point 3 inches behind the centre-line; and the link No. 4,
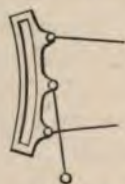
Fig. 376 (Link No. 2).   Fig. 377 (Link No. 3).   Fig 378 (Link No. 4).
Stationary Link: Various Points of Suspension.

fig. 378, sustained at a point 1½ inches behind the centre-line. The

motion-curves obtained are given in fig. 379; in strong lining for No. 2, and thin lining for No. 3. The motion-curves for No. 4 are given in fig. 380, in strong lining. By a scale of 100 parts appended to fig. 375, and applicable
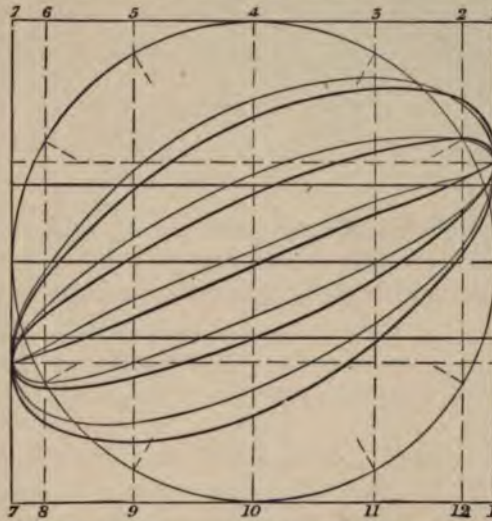
Fig. 379.—Motion-curves for Stationary Links Nos. 2 and 3.
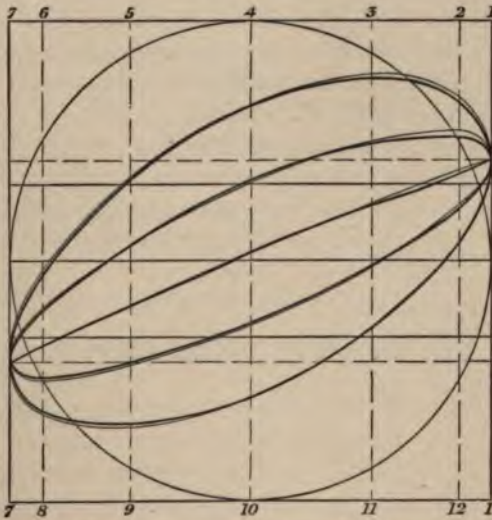
Fig. 380.—Motion-curves for Stationary Links Nos. 4 and 5.

to the other figures, it is found that the motion-curves yield the following periods of admission, measured by the horizontal progress of the crank. Nos. 1 and 2, it is seen, operate reversely, as the back stroke, in the first case, and the front stroke, in the second, admit the greater quantity of steam. The periods of admission, in the two cases, are merely the same quantities simply exchanged. No. 3 contrasts with the previous cases, by the extreme inequality of the admissions.

Stationary Link—Periods of Admission.

LINK.	Full-gear Forward.		Half-gear Forward.		Mid-gear Forward.	
	Front Stroke.	Back Stroke.	Front Stroke.	Back Stroke.	Front Stroke.	Back Stroke.
	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.
No. 1	73½	76	45	50	10	12¼
No. 2	76	73½	50½	46	14	10½
No. 3	69½	77½	38	55	9½	13½
No. 4	72½	76	41½	52	10	12

Selecting the admissions for half-gear forward, sufficient for the purpose of comparison, and correcting them for the unequal obliquity of a connecting-rod six times the length of the crank, they become as follows:—

Link, Half-gear Forward.	Front Admission.	Back Admission.
No. 1	48¼ per cent.	45¾ per cent.
No. 2	54¾ „	41¾ „
No. 3	42 „	50¾ „
No. 4	45½ „	47¾ „
No. 5	46½ „	46¼ „

No. 4, evidently, approximates most nearly to equal admissions, simply in virtue of an adjustment of the centre of suspension. By moving the suspension-centre a little nearer to the centre-line—to a position 1 3/16 inches from it—the admissions become exactly equal, as noted above for No. 5 design, and shown in fig. 380, in light lining.

For the three positions of full-gear, half-gear, and mid-gear forward, the mean periods of admission and expansion are as follows:—

No. 5.	Mean Admissions.	Mean Expansions.
Full-gear	74.5 per cent.	16.5 per cent.
Half-gear	46.4 „	32.0 „
Mid-gear	12.0 „	38.0 „

Set off on the base-line A B, fig. 381, the percentages of admission, and draw ordinates equal to the values of the expansions. The curve traced through the extremities of these ordinates, as was done for the case of a single-eccentric motion, in fig. 365 page 11, shows how the period of expansion increases as admission is reduced by
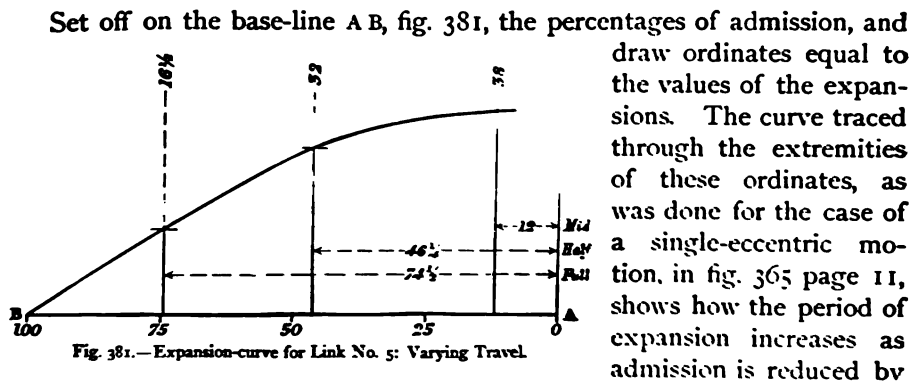
Fig. 381.—Expansion-curve for Link No. 5: Varying Travel.

the link. This curve is virtually identical with that for the single-eccentric motion, for the same lap, lead, and travel—the travel having in the

two cases the maximum and minimum values, 4½ inches and 2⅝ inches. Compare the actual values, as percentages of the stroke, as follows:—

Comparative Distribution by a Single Eccentric and by Link-motion No. 5.

Lap 1 inch; lead 5/16 inch.

TRAVEL.	ADMISSIONS.		EXPANSIONS.	
	Single Eccentric.	Link.	Single Eccentric.	Link.
inches.	per cent.	per cent.	per cent.	per cent.
4½	73.5	74.5	17.5	16.5
2⅝	12.0	12.0	38.0	38.0

The contents of this tablet indicate an identity of action, and they show that a correct link-motion is essentially the same in operation as a single-eccentric motion, having the same lap, lead, and travel.

The suspended link-motion, designed by Sir Daniel Gooch about the year 1843, for the Great Britain locomotive and other classes of engines on the Great Western Railway, is shown in fig. 382. It yields perfectly equal admissions and expansions for all the positions of the gear. The eccentrics have 5¼ inches of throw, the fore eccentric-rod is 4 feet 9½ inches long, the back eccentric-rod is 4 feet 10 inches, the lap outside is 1¼ inches, and inside 1/16 inch, the lead is ⅜ inch, and the travel of the valve in full-gear forward is 4¾ inches, cutting off at two-thirds of the stroke.

THE SHIFTING LINK.

The shifting link-motion is illustrated by fig. 383. The reversing gear operates on the link, by shifting it vertically on the block, which is confined by guides to the centre-line of the valve-motion, as indicated generally by the diagram. The dimensions and literal references of the stationary link-motion, page 14, are retained in the motion here illustrated.

The vertical movement of the link, for regulating the admission, takes place round the two distinct centres of the eccentrics. Thus a compound radial movement takes place, resulting in a variation of lead,—greater as the admission is less. The variation of lead is equalized for the front and back strokes, by curving the link to the radius of the eccentric-rods,
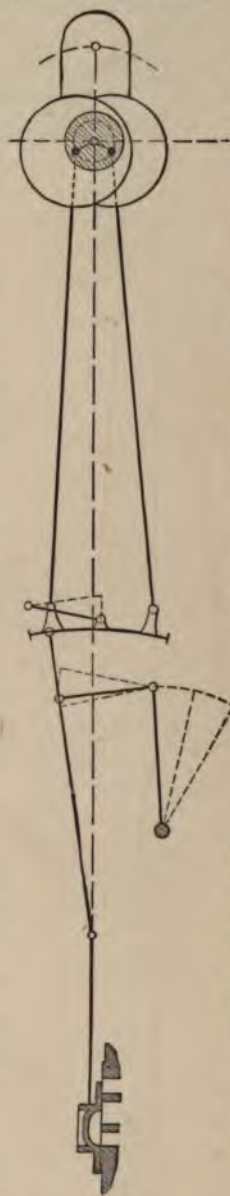
Fig. 382.—Stationary Link-motion, by Sir Daniel Gooch. Eccentrics, 2⅝ in. radius.—Fore rod, 4' 9½".—Back rod, 4' 10".—Lin. advance of fore eccentric, 1.19 in.—Do. back eccentric, 1.15 in.—Lap outside, 1¼ in.—Do. inside, 1/16 in.—Lead, ⅜ in.—Travel in 1st notch, 4¾ in.

concavely to the axle. To trace the action of the shifting link on the lead, let
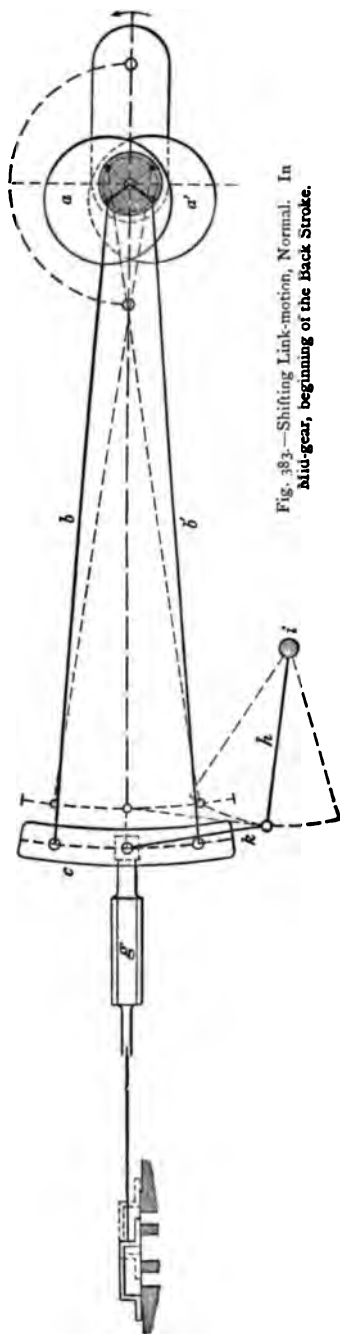
Fig. 383.—Shifting Link-motion, Normal. In Mid-gear, beginning of the Back Stroke.
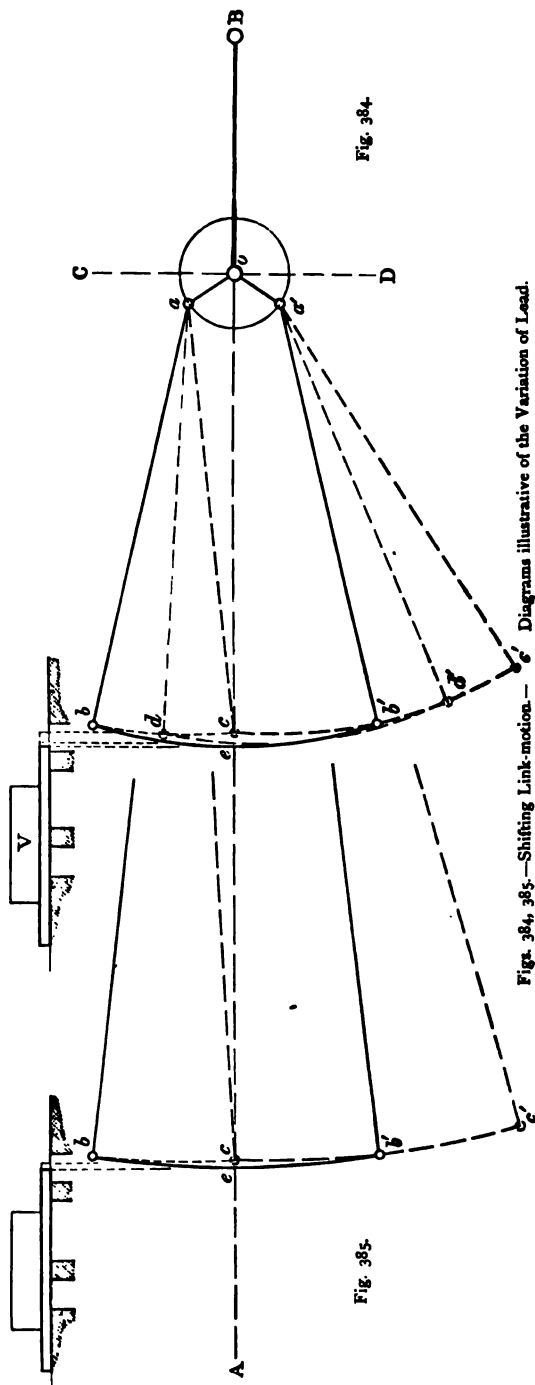
Fig. 384.

Fig. 385.

Figs. 384, 385.—Shifting Link-motion.— Diagrams illustrative of the Variation of Lead.

A B, figs. 384 and 385, be the centre-line of the link-motion; C D, fig. 384, a

vertical through the centre of the axle; oB the position of the crank for the beginning of the back stroke; oa, oa', the radii of the eccentrics, $2\frac{1}{4}$ inches; ab, $a'b'$, the eccentric-rods, 18 inches long, or eight times the radius of the eccentrics, and bb', the link of 12-inch centres, and curved to an 18-inch radius. The strong lines show the position of the motion in mid-gear, in which case the centre e of the link coincides with the centre-line A B. Lowering the link into full-gear forward, in the position cc', in which the upper centre is brought into the centre-line at c, the point c falls within the first position of the link by the amount ce; and as the block engages with the link at the points e and c respectively, it follows that the lead in mid-gear is greater than that in full-gear by the length ec. In half-gear the link dd' cuts the centre-line at a point between e and c. It thus appears that the lead is progressively reduced, from mid-gear to full-gear.

With eccentric-rods of double the length,—36 inches; and a link of 36-inch radius, the valve-motion, fig. 385, indicates a diminished variation of lead to the extent of about one-half. With a shorter link, also, the variation of lead becomes less; and, generally, the shorter the link, and the longer the eccentric-rods, the less is the variation of lead.

For the front stroke, likewise, the lead is varied with the position of the link, as exhibited in fig. 386, where $b''b'''$ is the position of the link in mid-gear, for the front stroke; and it appears to be the same in extent as for the back stroke. As the obliquity of the rods ac and $a''c''$, is the same, the interval cc'', which is twice the linear advance of the valve in full-gear, is equal to the horizontal interval between the points a and a'', or to the direct interval aa''', which is twice the
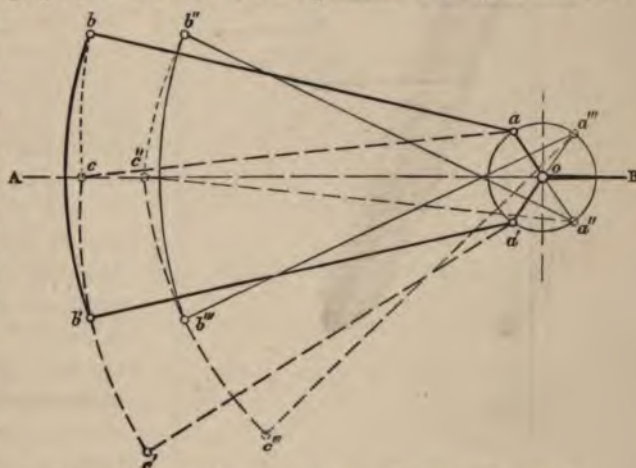
Fig. 386.—Shifting Link-motion.   Diagram illustrative of the Variation of Lead, and of Linear Advance.

linear advance of the eccentrics. As this equality is not affected by the length of the rods, it follows generally, that, for the shifting link-motion, the linear advance of the eccentrics is equal to that of the valve in full-gear. For the 54-inch rods, the lead, being $5/16$ inch in full-gear, becomes $9/16$ inch in mid-gear.

The shifting link, like the stationary link, is sensitive to the position of the point of suspension. But, whilst, in general, the stationary link should be hung by a centre near the middle of its length; the shifting link may effectively be hung by a centre towards one of the extremities.
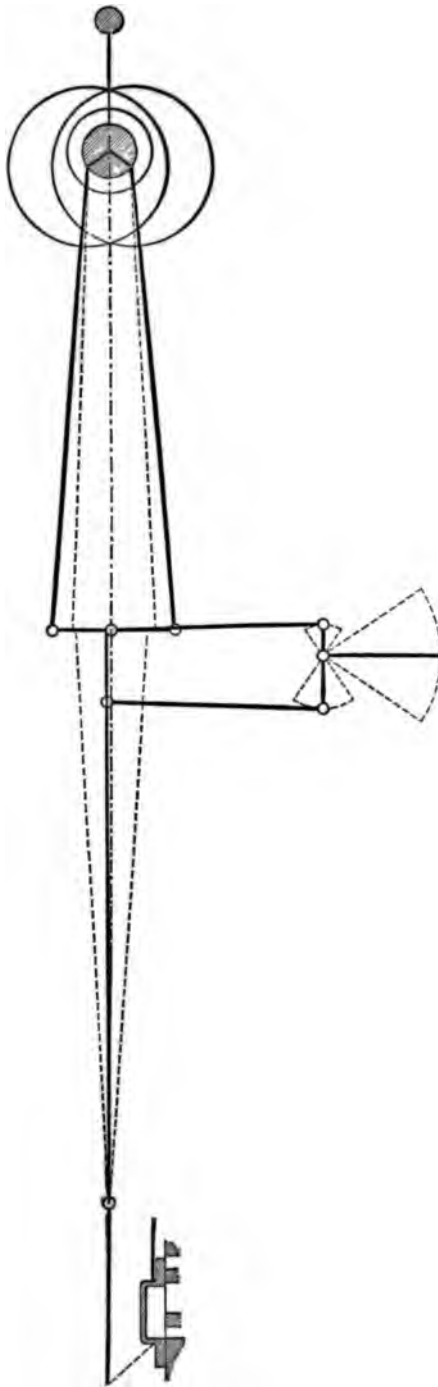
Fig. 387.—Straight-link Motion, by Mr. Alexander Allan. Eccentrics 4½ inches throw, Rods 39⅝ inches. Link, 10 inches long. Lap of Valve 1 inch, Lead ¼ inch. Scale 1/16th.

THE STRAIGHT-LINK MOTION.

Mr. Alexander Allan's modification of the link-motion, fig. 387, is a combination of the stationary-link and the shifting-link motions. The link is not curved either one way or the other, but is straight. It is raised and lowered in opposition to the radius-link, which is correspondingly lowered and raised, so that the vertical range of either the link or the block is less than that of either in the other two systems of link-motion. The radius-link and expansion-link are both suspended or supported at the ends of a lever on the reversing-shaft, by turning which they are moved simultaneously. In the motion shown by fig. 387, the eccentrics have 4½ inches of throw, the rods are 39⅝ inches long, the link is 10 inches long, the travel of the valve is 4½ inches, the lap is 1 inch, and the lead is ¼ inch, and is constant for all positions of the gear. The steam is cut off at 75 per cent of the stroke. The gear here illustrated was constructed for a locomotive engine, having 16-inch cylinders with 22 inches of stroke.

RULES FOR VALVE-MOTION.

The distribution derivable from the motion of an eccentric, communicated directly to the slide-valve, may be calculated in terms of the lap, lead, and travel of the valve. The inequalities caused by the varying obliquity of the connecting-rod are not now recognized. The valves may be adjusted so as to neutralize their influence.

For the Angular Advance of the Eccentric.

$$\frac{\text{linear advance}}{\text{half-travel}} = \text{sine of angle of advance,}$$

from which the angle may be found in a table of natural sines.

For the Point of Suppression or Cut-off.—This point occurs when the steam side of the valve arrives at the outer edge of the steam-port, and a part of the half-travel equal to the lap remains to be described. Now,

$$\frac{\text{lap}}{\text{half-travel}} = \text{sine angle of eccentric}$$

at the instant of cut-off. This angle, measured from the commencement of the throw, is obtuse; and, selecting the greater value of the sine, given in a table of sines, the difference of the angle so found and the angle of advance measures the angle of the crank at the point of cut-off.

If the length of the crank, or half-stroke, be taken equal to 1, the cosine of the angle of the crank expresses the position of the piston with reference to half-stroke. The cosine must be added to 1, if the angle be obtuse, or subtracted from 1 if acute, to give the position with reference to the beginning of the stroke. In brief—

angle of eccentric – (minus) angle of advance = angle of crank,

and,

1 ± cosine angle of crank = position of cut-off in terms of half-stroke.

For the Point of Admission.—This point occurs when the valve has passed its middle position by a length equal to the lap. Then—

$$\frac{\text{lap}}{\text{half-travel}} = \text{sine angle of eccentric.}$$

This angle is acute, and,

angle of advance – angle of eccentric = angle of crank.

and,

1 – cosine angle of crank = position of point of admission.

For the Point of Release or Exhaust.—Should there be neither lap nor clearance inside, the release commences when the valve is at half-travel. The eccentric is then on the datum-line, and the crank is by as much as the angle of advance from the end of the stroke; thus,

1 + cosine angle of advance = position of piston at point of release.

With inside lap or clearance,

$$\frac{\text{lap or clearance}}{\text{half-travel}} = \text{sine angle of eccentric;}$$

whence the angle, which is subtracted from the angle of advance if due to lap, or added if due to clearance. The result is the angle of the crank; or,

angle of advance ± angle of eccentric $\left(\begin{array}{l} \text{for clearance} \\ \text{for lap} \end{array} \right)$ = angle of crank;

and,

1 + cosine angle of crank = position of piston.

For the Point of Compression.—When there is no inside lap or inside clearance, compression, like release, occurs when the valve is at half-travel. The eccentric is then on the datum-line, and the crank is distant from the beginning of the stroke by as much as the angle of advance; thus—

$$1 - \text{cosine angle of advance} = \text{position of piston.}$$

Inside lap or clearance becomes the sine of the angle of the eccentric, and this angle is accordingly added to or subtracted from the advance. Or—

$$\text{angle of advance} \pm \text{angle of eccentric} \left(\begin{matrix} \text{for lap} \\ \text{for clearance} \end{matrix} \right) = \text{angle of crank;}$$

and,

$$1 - \text{cosine angle of crank} = \text{position of piston.}$$

The similarity of the four processes above indicated is apparent. In all cases the lap or the clearance divided by the half-travel yields the sine of the angle of the eccentric due to the points of the distribution:—outside lap being employed in settling the first two points, and inside lap or inside clearance for the second two. Inside lap and clearance are rarely used, and, indeed, are not necessary; and they are not considered in the framing of the following rules. The second operation is to deduce the angle of the crank from the angle of the eccentric and the advance conjointly, the sum or the difference being taken as required.

The foregoing operations are expressed in verbal rules as follows— given the lap, lead, and travel of the valve:—

RULE 1. *For the Angular Advance.*—Divide the linear advance by the half-travel; the quotient is the natural sine of the angle of advance; whence the angle, which is acute, may be found in a table of natural sines.

RULE 2. *For the Point of Suppression or Cut-off.*—Divide the lap by the half-travel of the valve, and the quotient is the natural sine of the angle of the eccentric at the instant of cut-off; whence the angle, which is obtuse, may be found in the table. From the angle of the eccentric, so found, subtract the angle of advance found by Rule 1; the difference is the angle of the crank. If this angle be obtuse, add 1 to its natural cosine; if acute, subtract the cosine from 1. The sum or the difference, so found, multiplied by 50, gives the period of cut-off, or the period of admission, in percentage of the stroke.

RULE 3. *For the Point of Admission.*—Subtract the angle of the eccentric, found by Rule 2 (being in the present case acute), from the advance; subtract the cosine of the difference, so found, from 1; the remainder multiplied by 50 gives the position of the point of admission, in percentage of the stroke.

RULE 4. *For the Release or Exhaust.*—Add 1 to the cosine of the angle of advance, and multiply the sum by 50; the product gives the place of the release or exhaust in percentage of the stroke.

RULE 5. *For the Compression.*—Subtract the cosine of the angle of advance from 1, and multiply the remainder by 50; the product gives the place of the compression, in percentage of the stroke. Or, subtract the period of release from 100; the remainder is the place or the period of compression.

Example.—Take the case of a slide-valve, having 4½ inches of travel, 1 inch of lap, and 5/16 inch of lead; worked by a single eccentric. To find the period of admission or the point of cut-off. To find, first of all, the angle of advance, by Rule 1. The linear advance $= 1 + 5/16 = 21/16$ inch; and the half-travel $= 36/16$ inch; then $21/36 = .583 =$ sine angle of advance $= 36°$, by table of natural sines. Again, by Rule 2, as the lap $= 4/4$ inch, and the half-travel $= 9/4$ inch; $4/9 = .444 =$ sine angle of eccentric at the point of cut-off. This corresponds in the table of sines to 26°, or its complement, 154°; and, as the angle of the eccentric is always obtuse, the greater value is selected. Then, $154° - 36° = 118° =$ angle of crank at the point of cut-off. The cosine of 118°, or its complement 62°, is .469. Adding 1, the sum is 1.469; and $1.469 \times 50 = 73.4$ per cent of the stroke, which is the mean period of admission due to the action of a simple eccentric.

The foregoing rules may be employed also for link-motions; and generally for all valve-motions which are based on the motion of eccentrics.

CHAPTER II.—HACKWORTH AND OTHER VALVE-GEARS.

HACKWORTH'S VALVE-GEAR.

In the reversible valve-gear, figs. 388, patented by Mr. John W. Hackworth, in 1859 and 1876, one eccentric only is employed. It is fitted with a short rod, the end of which is pinned to a pair of slide-blocks, which, according to the movements of the eccentric, reciprocate in a slide-frame, which, in the illustrations, comprises two sets of slides for a pair of engines. The frame is stationary when in action, but it is movable on pivots, and for this purpose it is formed with a worm-sector, which is engaged with a worm that may be turned by hand. The slide-frames are inclined to the horizontal centre-line through the main shaft, and the slides, therefore, reciprocate in an inclined path. The

Figs. 388.—Hackworth's Reversible Valve-gear, with one Eccentric.

eccentric-rod is thus impressed by two vertical movements, one at each

end, which, combining, result in a vertical movement of the valve-rod link, which moves the slider also. By adjustment of the incline of the slide-frame, the resultant vertical movement of the valve is modified, and the point of cut-off is varied. When the slide-frame is brought to a horizontal position, the vertical movement of the valve and its connections is a minimum; and when its inclination is reversed, the engine is thereby reversed. The valve-gear has good action and is compact; but the slide-movement is objectionable for wear and resistance; and the connection for the valve-link being located between the eccentric and the slide, an abnormally large eccentric is required to provide the required vertical movement.

THE BREMME VALVE-GEAR.

The Bremme valve-gear, patented by Mr. G. A. C. Bremme in May, 1879, introduces two modifications of the Hackworth gear:—1. The removal of the connection for the valve-rod link to the extremity of the eccentric-rod, and the placing of the oblique movement between the eccentric and the valve-rod link. 2. The substitution of a vibrating link for the inclined slide-frame. The Bremme gear, as usually applied to marine engines, is represented diagrammatically by figs. 389. The horizontal centre-line X X, No. 1 diagram, through the crank-shaft is intersected by the verticals C, Y, and Z, through the centres of the crank-shaft and the reversing shaft, and in the centre-line of the valve-spindle. The radius of the eccentric, K C, coincides with the crank. The end of the eccentric-rod K E is pinned to the valve-rod link E T, and about midway, at H, it is suspended by a link G H from the end of an arm F G on the reversing shaft F. The link and the reversing arm are equal in length, and the path of the lower end of the link, oscillating from the end of the arm G, intersects the horizontal centre-line X X at the centre of the reversing shaft F in all positions of the reversing arm. The intersection and the momentary coincidence of the centres H and F of the link and the reversing shaft, occur twice in each revolution of the crank-shaft, when the crank is at the dead-points, the end of the link vibrating equally on both sides of the shaft.

The reversing arm is, in No. 1, placed in full-gear forward at an angle of 25 degrees with the vertical, which should not be exceeded. By reducing the angle, steam is cut off earlier, and by shifting the arm to the other side of the vertical the engine is placed in backward gear.

The dot-lines show the positions of the eccentric-rod when the crank is on the dead-points. They intersect each other at the axis of the reversing shaft, with which the point H coincides. The points i, i, are the respective positions of the end of the rod, and the vertical distance of these points above and below the horizontal centre-line is a measure of the lap plus the lead of the valve. The lead is constant for all degrees of admission and expansion. The closed curve E $i\,i$—the oscillation curve—is described by the end of the eccentric-rod; and that of the valve-rod link during each revolution of the crank; and the ordinates of the curve represent the movements of the valve.

As the end H of the suspending link moves in a circular arc its divergence from the centre-line X X is less below the line than it is above. The oscillation curve, in consequence, is unsymmetrical, and the valve-motion
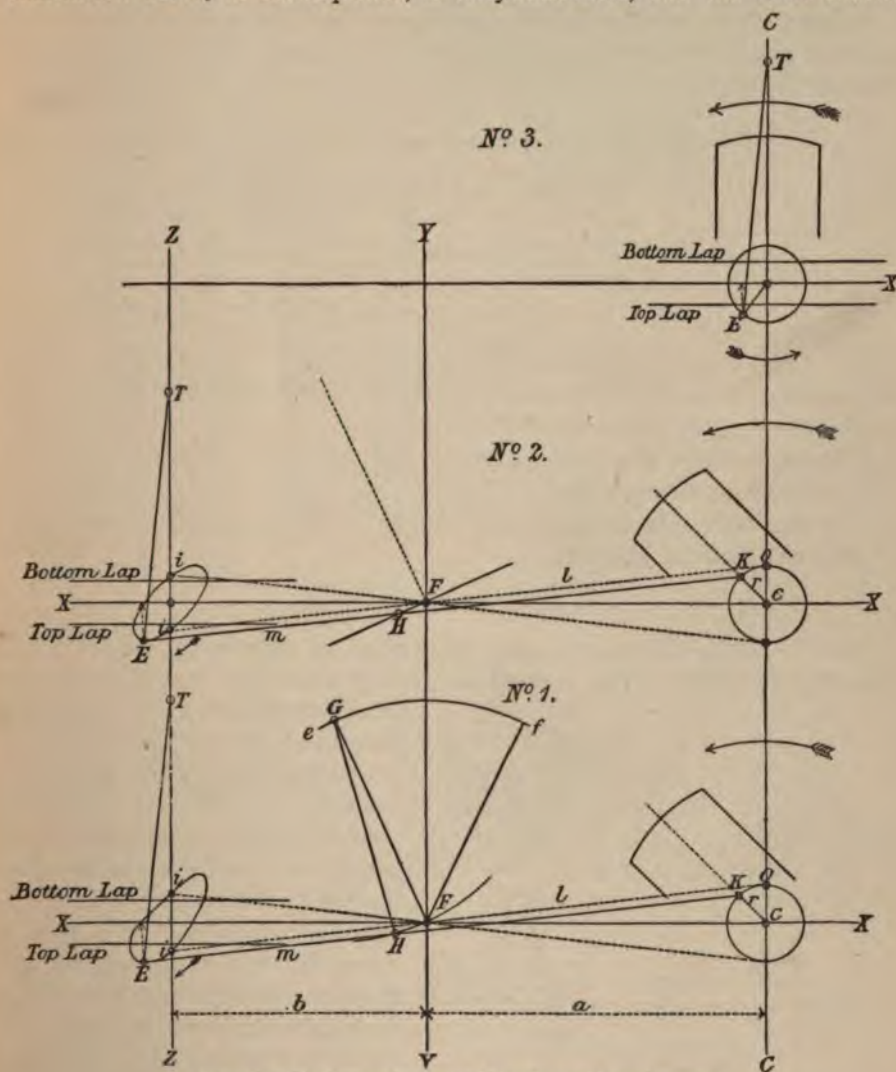
Figs. 389.—The Bremme Reversible Valve-Gear, with one Eccentric.

is assimilated to the irregular motion of the piston caused by the varying obliquity of the connecting-rod.

In No. 2 diagram, figs. 389, the path H F of the centre H in the eccentric-rod is an oblique straight line instead of an arc, corresponding to a suspending link of infinite length, or to a straight sliding guide, as before employed by Hackworth. The oscillation curve is, in this case, symmetrical.

No. 3 diagram, figs. 389, represents the conditions of a simple eccentric movement, the crank being at the upper dead-point.

The subjoined table, No. 165, drawn up by Mr. Bremme, exhibits the positions of the crank, and the periods of admission, exhaust, compression, and pre-admission. The conditions—putting $r =$ the radius of the eccentric —are that $a = 7r$, $b = \frac{3}{4}a$, the reversing arm and suspending link $= 6r$, in figs. 389; angle of the reversing arm $= 24°$; lead $= \frac{3}{4}r$, lap $= \frac{9}{16}r$; angular advance of eccentric, in link-motion, $= 48° 36'$; connecting-rod $= 4$ cranks.

Table No. 165.—BREMME GEAR AND OTHER GEAR-DISTRIBUTION.

Points of the Distribution.	Bremme.—No. 1.				Straight Guide.—No. 2.				Link-motion.—No. 3.			
	Down-stroke.		Up-stroke.		Down-stroke.		Up-stroke.		Down-stroke.		Up-stroke.	
	angle.	per cent.	angle.	per cent.	angle.	per cent.	angle.	per cent.	angle.	per cent.	angle.	per cent.
Cut-off.............................	96°	61.5	110°	61.5	108°	71.2	108°	59.7	98°	63.2	98°	50.7
Exhaust and Compression..	133°	87.4	137°	89.5	140°	90.9	130°	78.4	132°	86.9	132°	79.9
Pre-admission	168°	99.1	167°	99.0	168°	99.1	165°	97.8	166°	98.9	166°	98.1

It appears from the table that the Bremme gear produces a perfect distribution, with constant lead.

The Bremme gear is illustrated further on in its application to Yacht Engines and Launch Engines.

MARSHALL'S VALVE-GEAR.

Mr. F. C. Marshall's valve-gear, as applied in marine engines, is illustrated by figs. 390. The motion is derived from one eccentric on the crank-shaft, with a comparatively short rod or bar, from an intermediate point in which the valve receives its travel through the valve-rod link. The eccentric is set on the shaft exactly at right angles to the crank. The outer end is suspended by a link j from the arm k, keyed on the reversing shaft l; and it vibrates by the movement of the eccentric in the arc indicated by dotting. The arm and the link are equal

Figs. 390.—Marshall's Reversible Valve-gear, with one Eccentric.

in length, and the end of the eccentric-rod coincides, at half vibration, with the centre of the reversing shaft, at the beginning of each stroke, when the valve is in position for the linear advance. The travel of the valve is derived from the obliquity of the arc of vibration of the end of the eccentric-rod, by which the end is raised and lowered, in combination with the vertical movement of the eccentric. To cut off earlier, the arm k is elevated towards the upright position, when the arc of vibration approaching more nearly to a horizontal direction and becoming less oblique, the

vertical movement of the end of the eccentric-rod, and correspondingly the travel of the valve, are reduced. When the arm k is raised to the vertical position, the arc of vibration lies practically in a horizontal line, the end of the eccentric-rod is maintained at one level, and the travel of the valve is derived solely from the vertical movement of the eccentric. To reverse the engine, the arm k is shifted to the other side of the shaft into the position indicated by dot-lines. Thus the variation of expansive working and the reversing are effected essentially by shifting the point of suspension or fulcrum for the swinging link j from one side of the reversing shaft towards or to the other side.

Constant lead and equal periods of admission are effected by this motion. It appears to have arisen out of the original invention of John W. Hackworth.[1]

WALSCHAËRTS' VALVE-GEAR.

The Walschaërts gear, shown in fig. 391, applied to a locomotive, is in use, to some extent, in locomotives on Continental railways. It was introduced by M. Walschaërts in Belgium, and by Herr Hensinger von Waldegg in Germany. It has also been applied to locomotives on the Northern Railway of France. The motion of the valve is the resultant of two
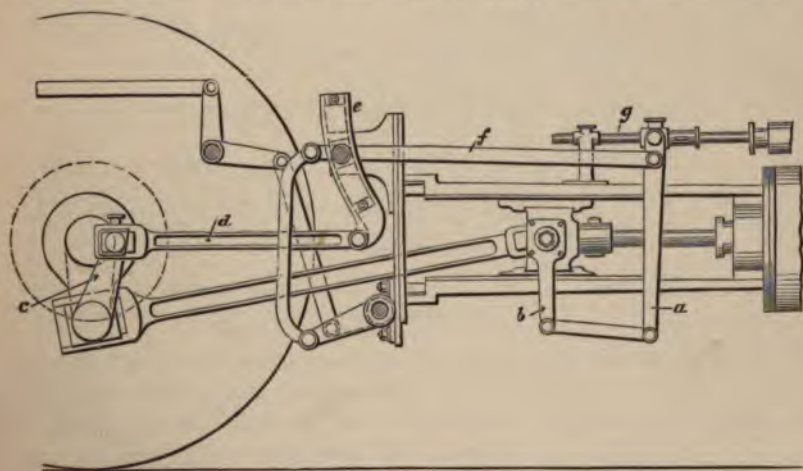
Fig. 391.—Walschaërts' Valve-gear.

movements, of which one is designed specifically to place the valve in position for the beginning of each stroke, with a constant lead for all lengths of travel; and the other is designed to give the required travel to the valve. The first of these objects is attained by means of the lever a, the lower limb of which is linked to a stud-bar b, fixed to the crosshead, by which it is reciprocated with a vibration equal to the stroke of the piston. The upper limb is very short, and is so proportioned as to recipro-

[1] See discussion on Mr. Joy's paper, on a "New Reversing and Expansive Valve-gear," in the *Proceedings of the Institution of Mechanical Engineers*, August, 1880, page 430.

cate the valve-spindle *g*, through a space equal to twice the linear advance, and thus to place the valve in position with constant lead at the beginning of the stroke. The second and superposed movement is derived from an eccentric or an overhung crank-pin *c*, on the driving-axle, by which a reciprocating movement is communicated through the rod *d* to a slotted sector *e*, which is pivoted at its centre. The motion of the sector is communicated through the radius-link *f* to the fulcrum of the lever *a*, and thence to the valve-spindle. The sector is curved to a radius equal to that of the radius-link; and is fair with it at the beginning of each stroke, so that the lead remains the same whatever the position of the slide-block may be in the sector. The motion-curves yielded by this gear are like those of the link-motion.

BROWN'S VALVE-GEAR.

The valve-gear introduced, in 1877, by Mr. C. Brown, applied to tramway engines constructed at the Swiss Locomotive Works, Winterthur, is illustrated by fig. 392. The motion of the piston is transmitted through
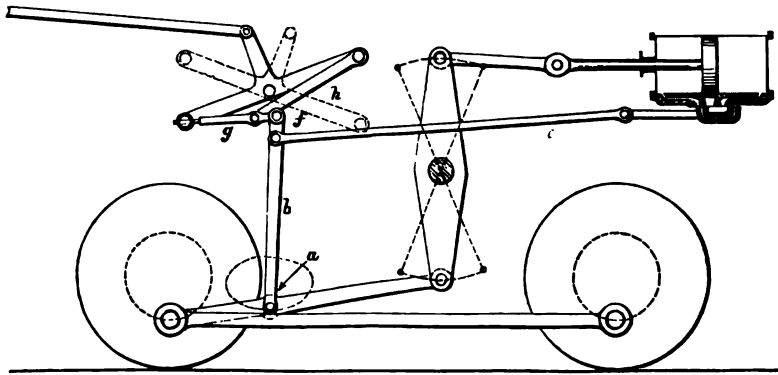
Fig. 392.—Brown's Valve-gear.

a rocking lever to the wheels, which are coupled. A constant lead of the valve, with a quick cut-off and a quick release, are obtained without the employment of eccentrics. The motion of the valve is composed of two movements, of which, as in Walschaërts' gear, one is designed to place the valve in position for the beginning of each stroke, and the other is designed to give the required travel of the valve. For these objects the motion is taken off the connecting-rod at the point *a*, where the lever *b* is attached. Following the motion of the connecting-rod, the lower end of the lever describes an elliptic curve, shown in dot-lining, of which the transverse axis, or horizontal movement, is equal to the length of the stroke of the piston; and the conjugate axis, or vertical movement, is, in the figure, about five-eighths of the transverse axis. The lever, on its fulcrum *f* at the upper end, acts on the valve through the radius-link *c*, connected to it at a point near to the fulcrum—so proportioned that the valve is set for constant lead at the end of each stroke, in the manner already described

for Walschaërts' gear. From the same lever, *b*, the required travel of the valve is given. Its fulcrum, *f*, is pinned to the end of a bar *g*, which is held in position at one end by the link *h*, pinned to the reversing lever, and at the other end by a sleeve, also attached to the reversing lever, in which the end of the bar is free to slide to suit the varying obliquity of the link *h*. The travel of the valve is obtained by the decomposition of the vertical movement of the lever *b*, which at the upper end is deflected laterally by the oblique play of the lever *h*; the lateral component of the motion, or lateral traverse of the fulcrum *f* of the lever, being communicated through the radius-link to the valve. The greater the degree of obliquity of the link *h*, which is adjustable by means of the reversing lever, the greater is the travel impressed upon the valve.

There is some degree of resemblance between the Brown gear and Walschaërts' gear:—in the first part of the motion. But they are clearly distinguished by the total absence of eccentrics or small cranks in the Brown gear, and the mode of taking off the travel by means of an oblique link.

KITSON'S VALVE-GEAR.

The valve-gear employed by Mr. J. H. Kitson, in tramway locomotives, fig. 393, is simply a modification of Walschaërts' gear, fig. 391. Instead of an eccentric or return-crank of small throw, employed by Walschaërts for
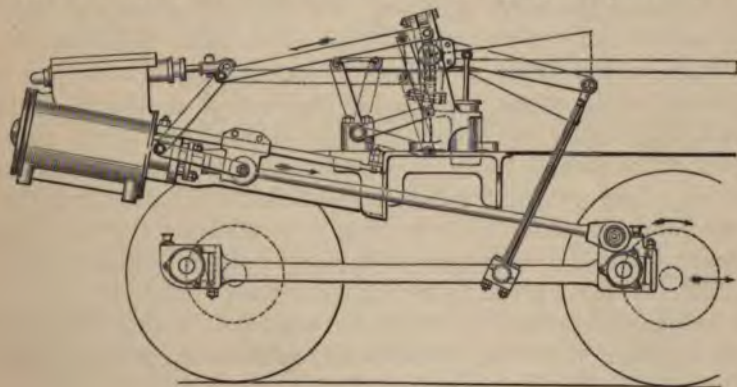
Fig. 393.—Kitson's Valve-gear.

reciprocating the slotted sector, Mr. Kitson takes his motion from the coupling-rod by a link which is pinned to the end of a long arm fastened to the back of the sector.

JOY'S VALVE-GEAR.

The valve-gear introduced by Mr. David Joy, in 1880, fig. 394, is designed, like Brown's and Kitson's gear, to give a constant lead of the valves with a quick cut-off and a quick release, without the employment of eccentrics. The motion is taken off the connecting-rod at the point *a*, where the link *b* is attached. This link vibrates on the end of the link *c* as a fulcrum, this link itself vibrating on a fixed fulcrum *c'*. Following the motion of the

connecting-rod, the upper end of the link *b* describes an elliptic close curve, shown in dot-lining. A secondary lever *e* is pinned to the first lever at a point *d*, about one-third of the length from the upper end. The movement of the point *d* is shown in dot-lining, forming an ellipse of shorter range
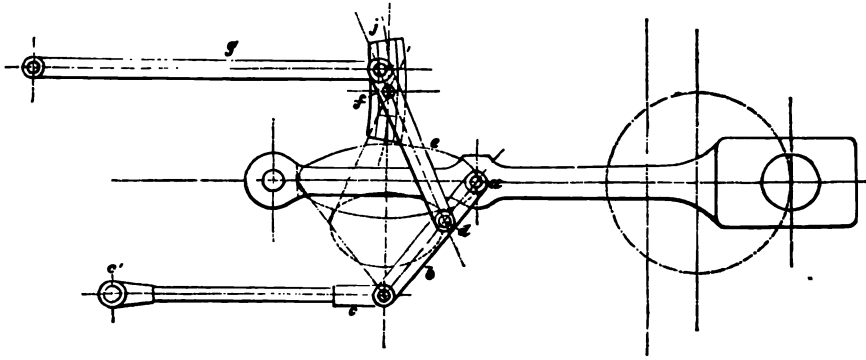
Fig. 394.—Joy's Valve-gear.

than, but of equal height with, that for the point *a* in the connecting-rod. The lever *e*, through the fulcrum *f*, and its short limb, acts on the valve through the radius-link *g*, giving constant lead, in the manner already described for Walschaerts' gear, and the others. From the same lever the required travel of the valve is given. Its fulcrum carries a sliding block, which is movable in the slotted sector *j*. This sector is adjustable on its own fulcrum to any angle of obliquity, and the block travelling up and down the slot of the sector, in virtue of the vertical motion of the lever *e*, takes with it the upper end of this lever, from which the lateral component of the motion, or lateral travel, is communicated through the radius-link *g* to the valve. The greater the degree of obliquity, the greater is the travel impressed upon the valve. The gearing is so adjusted that the fulcrum *f* of the lever *e* coincides with that of the sector, at the dead-points of the crank. The sector is curved to the radius of the radius-link.

The oblique movement in the sector employed by Mr. Joy for generating the travel of the valve, is practically identical with that obtained by the oblique link in Mr. Brown's gear.

CHAPTER III.—AUTOMATIC EXPANSION VALVE-GEAR.

GALLOWAYS' VALVE-GEAR.

A slotted link-motion which has been much employed by Messrs. Galloways for varying the cut-off is shown in fig. 395, as applied to their horizontal compound steam engine. The slot-link is supported by a pair of vibrating links, and is driven by a small crank on a weight-shaft, in the line of the main shaft, driven by a drag-link from the main crank-pin. The slot-link is curved to the radius of the radius-rod or valve-rod

link, and engages a block on the end of this rod. The position of the block in the slot is determined by the governor, and thence the travel of the valve, and the cut-off, which increase with the distance of the block above the fulcrum. The cylinder and ports with the cut-off valves are shown sectionally in place. There are two short straight ports, one at each end of the cylinder, and a cut-off valve to each port, the valves being fixed on one rod or spindle. The engine is illustrated and described, p. 179.

The governor is peculiar. It is a weighted parabolic governor, fully described elsewhere, and is fitted with an oil cylinder for the purpose of arresting the fluctuations of level to which the block in the slot is liable, in consequence of the varying obliquity of the slot. The vertical range of the governor is doubled at the block, by leverage.

HORNSBY'S AUTOMATIC EXPANSION-VALVE AND GOVERNOR GEAR.

The expansion gear of Messrs. R. Hornsby & Sons, fig. 396, is applied to a special expansion-valve on the back of the main slide-valve of the engine. The motion is derived from a single eccentric on the main shaft, the rod of which is pinned to an upright rocking slotted link, pivoted at its lower end to the frame. The vibratory motion of the link is constant, and its movements are communicated by means of a radius-link to the expansion-valve and its spindle. The radius-link carries a block which is capable of sliding upwards or downwards in the slot of the link, by which the travel of the expansion-valve is varied according to the elevation of the block above the pivot. The elevation of the block in the link is controlled by a governor, in the sleeve of which the end of a short arm is engaged, on the shaft of which an eccentric is fixed. As the governor rises or falls, the eccentric falls or rises correspondingly, and
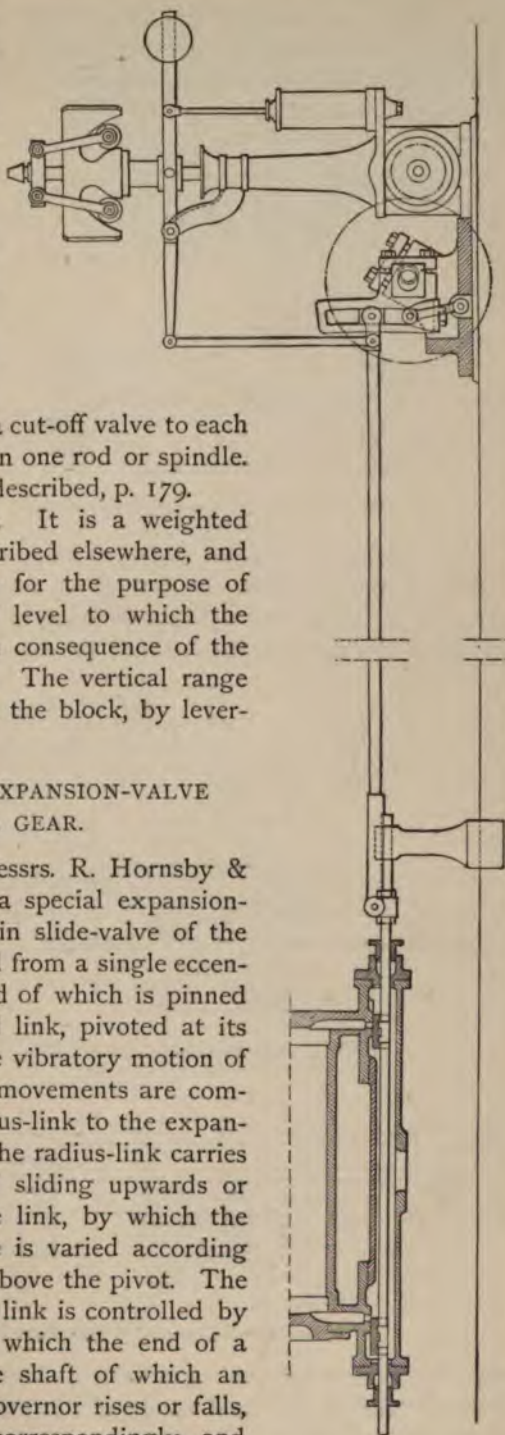
Fig. 395.—Galloway's Automatic Expansion-valve and Governor Gear.

raises or lowers a lever of the third order, in which the fulcrum is at one end, the connection of the eccentric-rod is near to it, and the connection to the radius-link is at the other end. By this means, so long as the
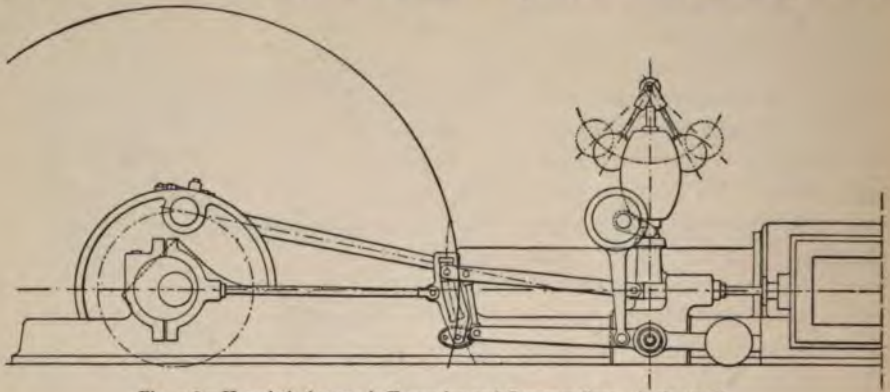
Fig. 396.—Hornsby's Automatic Expansion and Governor Gear. Scale 1/24th.

working parts are in good order, without slackness, the slightest vertical shifting of the eccentric is multiplied six times at the far end of the lever, and a correspondingly great range of the sliding block in the slot is provided. As the eccentric cannot be moved by the stress of the valve-
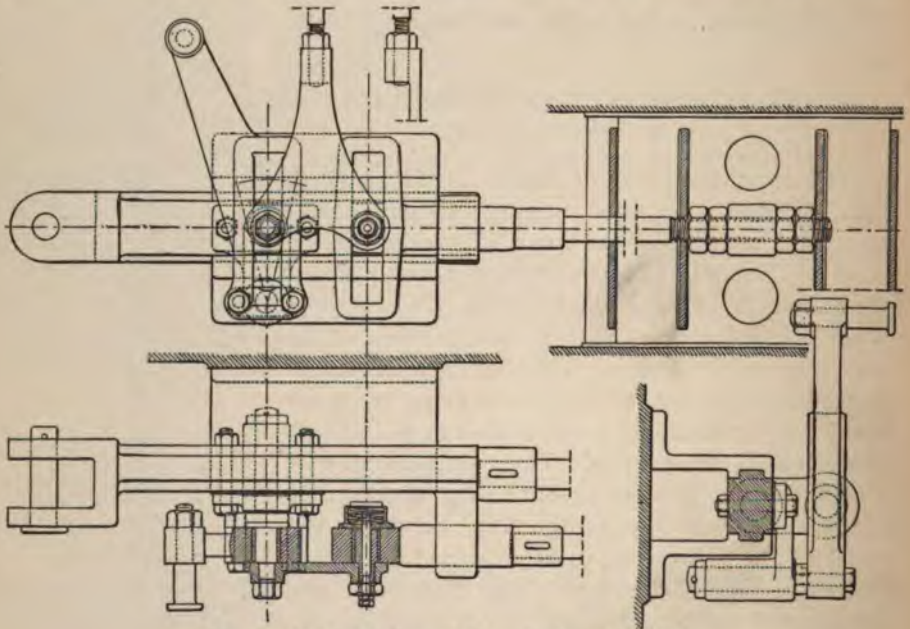
Fig. 397.—Holborow's Automatic Expansion Gear. Scale ⅙th.

gear, the motion of the gear is free from the unpleasant vertical slip which prevails in the usual forms of slot-link expansion gear. Steadiness is here combined with sensitiveness.

HOLBOROW'S AUTOMATIC EXPANSION GEAR.

In this gear, fig. 397, an expansion-valve is superposed on the main valve. The main valve is worked direct by an eccentric on the main shaft. The expansion-valve is worked by a separate eccentric on the main shaft, set at a small angle with the main eccentric. It is connected to the upper end of a slotted lever, which vibrates on a pivot at its lower end; in which a sliding block is adjustable vertically by the governor, according to the degree of cut-off required. The horizontal movement of the adjustable block is communicated through a triangular plate to the spindle of the expansion-valve: the spindle being formed with a transverse slotted head, in which a second sliding block is fitted, which is pivoted on the triangular plate. This plate is connected by its upper corner to the governor; and according as it is shifted vertically by the governor, the varying horizontal movement of the rocking lever is transmitted to the expansion-valve.

THE MEYER EXPANSION-VALVE.

The valve-gear, widely known as the Meyer gear, was introduced by Mr. J. J. Meyer, of Mulhouse, in 1842. It consists essentially of a main slide-valve, through ported at each end, and a pair of superposed slides, adjustable longitudinally, so as to vary the period of admission. The main
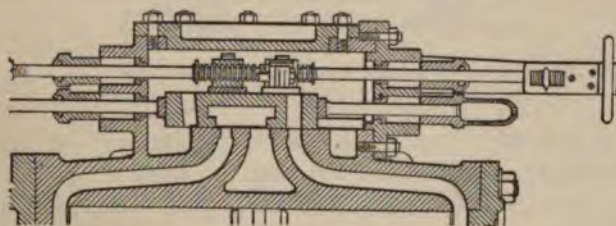
Fig. 398.—The Meyer Expansion-valve Gear. Scale 1/12th.

valve is so formed that steam is admitted to the cylinder, not at the extreme edges of the valve, as in ordinary valves; but through a passage or port in each end of the valve, by which the steam is conducted to the valve-face of the cylinder. The Meyer slides are moved independently of the main valve by a special eccentric, and the variation of the period of admission is effected without any variation of the travel, by the simple action of widening apart or of approximating to each other the two Meyer slides. This adjustment is effected by means of right-hand and left-hand screws on one spindle, passing through a stuffing-box to the outside, and mounted with a hand-wheel, by means of which the slides may be set by hand. The general design and arrangement of the Meyer gear is shown in fig. 398. The speciality of the Meyer gear is the promptitude with which the steam is cut off, compared with the action of a single eccentric motion. The quickness of the cut-off is the result of the combined movements of the two valves in contrary directions, and the relatively augmented

velocity of the approach of the expansion-slide to the outer edge of the through-port, when the cut-off is effected.

TRAPEZIUM EXPANSION SLIDE-VALVES.

The principle of the trapezium expansion-valve is that the steam-admitting edges are not parallel to each other, but are inclined to each other, forming a trapezium. The steam-ports are inclined to a like degree. Variable expansion is effected by shifting of the valve transversely, whereby it is caused to cut off the steam earlier or later according as it is shifted towards or from the shorter side of the trapezium. The trapezium valve-gear, constructed by the Erie City Iron-works, is shown in fig. 399. The steam-
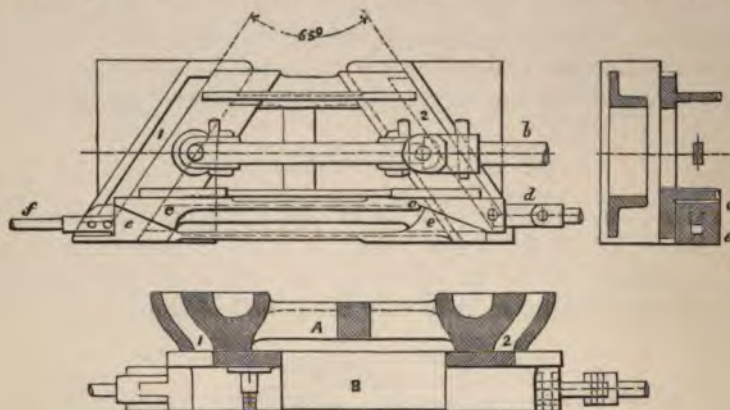
Fig. 399.—Trapezium Expansion Slide-valve, Erie City Iron-works.

ports 1 and 2 and the edges of the valve are inclined at the angle 65° towards each other; and it is obvious that the higher the trapezium valve is shifted the greater is the length of the valve, virtually, seeing that it cuts off the steam earlier in the course of the stroke. The valve is moved longitudinally by the spindle *b*, and it rests on the back of the double-wedge piece *cc* linked at *d* to the interior of valve-chest, and movable transversely by the longitudinal movement of the corresponding double-wedge piece *ee*. This piece can be shifted by means of the rod *f*, which passes through a stuffing-box and is fitted with a handle. The governor acts on a throttle-valve.

THE RIDER EXPANSION VALVE AND GEAR.

Mr. A. K. Rider, of New York, substituted a cylindrical trapezium and circular main valve for the flat trapezium and face just noticed, and he produces the transverse movement necessary for varying the admission by turning the cylindrical trapezium on its axis. The trapezium is shown by B, figs. 400, laid into the main valve A, in which *aa* are the steam-ports leading to the ports in the valve face of the cylinder. The spindle of the expansion-valve is concentric with it, and is flattened to take into the valve, as shown, for the purpose of turning it to the required extent. The

rotating movement of the valve-rod, for this purpose, is derived from the governor, which acts through a lever formed with a square eye fitting the spindle, which also is square; the spindle being free to slide longitudinally through the eye of the lever. The development of the expansion-
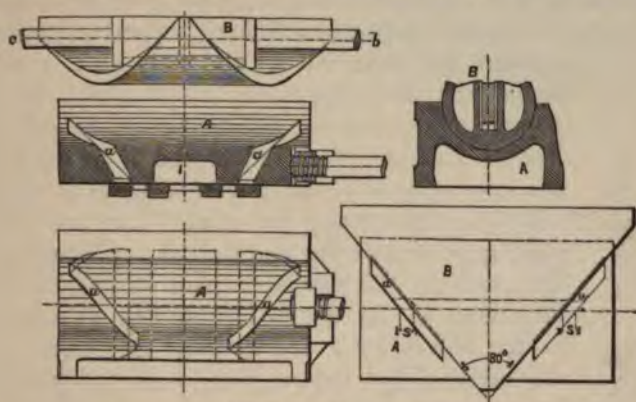
Figs. 400.—Rider's Cylindrical Trapezium Expansion-valve.

slide surface and main-valve surface is shown, at the right-hand side, in figs. 400.

Various other forms of valve-gear are illustrated and described farther on.

CHAPTER IV.—CORLISS AND OTHER VALVES AND SLIP-MOTIONS.

CORLISS VALVES AND GEAR.

The system of engine known as the Corliss engine was introduced by Mr. G. H. Corliss, in America, and patented in 1849, although it is understood that he constructed his first engine in the previous year. It is essentially a combination of elements previously known and used separately, affecting the cylinder and the valve-gear. Four independent ports are used for admitting and exhausting steam—one of each at each end of the cylinder. The steam is cut off by the steam-valves, without the employment of supplementary valves for the purpose. The steam-valves are opened against the resistance of springs, and a liberating gear is employed by which the steam-valves are disconnected, and left free to be closed by the action of the springs. After the valves are closed the springs are brought to a state of rest without shock, by means of the dashpot. This piece consists of a small cylinder open at one end and close at the other, in which a piston is fitted to work easily, and in which, by openings suitably arranged, air is free to circulate when the piston is moving, except when the piston approaches the bottom. At this time a certain quantity of air is imprisoned, forming a cushion to prevent any shock when the piston

reaches the bottom. The speed of the engine is regulated by the governor acting on the steam-valves to cut off the steam earlier or later, instead of on a throttle-valve, to vary the pressure of the steam. These are the five points of the Corliss gear; and Mr. William Inglis, in a paper on the subject,[1] points out that Seaward had previously constructed the cylinders

of marine engines with four separate ports and independent flat slide-valves; and that Sickles, in 1841, perfected the liberating gear and dashpot as applied to poppet or double-beat valves, in the cut-off gear which bears his name. Watt advocated, if he did not practise, the employment of the governor to vary the cut-off instead of wiredrawing the steam; and his disconnecting valve-gear, for opening and closing poppet-valves, discloses the germ of the Corliss expansion gear. That gear is illustrated by fig. 401. The motion was communicated to the valves by a rod A, the "plug-tree," attached to the beam of the engine, fitted with tappets BB, to open or close the valves C, when moving in one direction, and, in the opposite direction, to trip or liberate the catches D, by the curved lever E, and allow the weights F to act either for opening or closing the valves; the dashpot G being used for bringing the weight gradually to rest when dropped.

Fig. 401.—Watt's Disconnecting Valve-gear. Scale 1/24th.

The valve-gear first employed by Corliss is shown in fig. 402. A weight H, attached to a lever on the valve spindle I, supplied the external force for closing the valve, when the catch K was liberated, the weight

falling in a dashpot like that on Watt's gear. The tripping of the catch was effected by curving up the back end at K, which came in contact with a plate L, acted on by an inclined plane or wedge on the rod M connected with the governor. The plate L is raised or lowered according to the changes in the position of the governor balls. When it is lowered by excess of speed, the catch K is tripped sooner, steam is cut off earlier, and the supply reduced. The first steam engine fitted with Corliss gear was a beam-engine, in which flat slide-valves were used. The cylinder with the valve-gear is shown in fig. 403, without the application of the governor. The cut-off was adjustable during the working of the engine. The valves were moved by small rollers F, F, by means of toothed segments. The levers L on the shafts of these rollers were formed with catches, which took into notches on the motion-rods E, E, the other ends of which were pinned to and moved by an oscillating disc A, which derived its motion from an eccentric and its rod B, and which imparted the required reciprocating

Fig. 402. — Corliss Valve-gear. Earliest Form. Scale 1/24th.

[1] "On the Corliss Expansion Valve-gear for Stationary Engines," *Proceedings of the Institution of Mechanical Engineers*, 1868, page 177.

movement to the steam-valves, and also to the exhaust-valves F_1, F_2; with this difference, that the exhaust-valves were constantly in gear and in motion as ordinary slides, whilst the steam-valves were subjected to the action of the trip-gear. The motion-rods EE were pressed against the ends of the levers LL by the springs SS, and they were disengaged in coming into contact with the bolts RR. The degree of projection of these
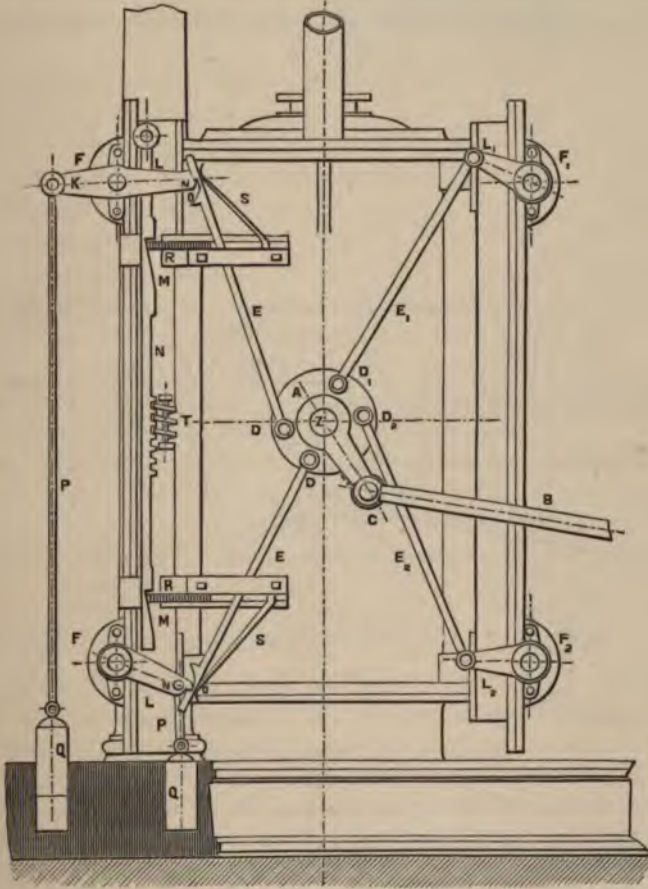
Fig. 403—Corliss Valve-gear. First Application to a Steam Engine.

bolts, and the consequent variation of the cut-off, were effected by adjustment of the bar N, vertically, being formed with inclined planes M, M, which acted on the bolts. The higher the bar N, the more the bolts approached the motion-rods, and the sooner these were pressed back and disengaged.

With the employment of liberating gear it became necessary that an independent force should be available for closing the valves when they were detached, and for this purpose weights were first used. But springs have since been substituted for weights, as they are quicker in action, effecting a sharper cut-off, and are better adapted for quick working.

There is an essential difference, it may be remarked, between the use of drop-valves and sliding valves in connection with liberating gear. In the one case, as in the Sickle gear, the dashpot is applied to arrest the valve itself and prevent it from striking its seat; in the other case, it is only required to prevent the concussion of the weight or spring that is used to close the valve. But the drop-valve, in being lowered to its seat, is made to fall slowly as it approaches its seat, and there must be a degree of wiredrawing of the steam when cut off. With the slide-valve, on the
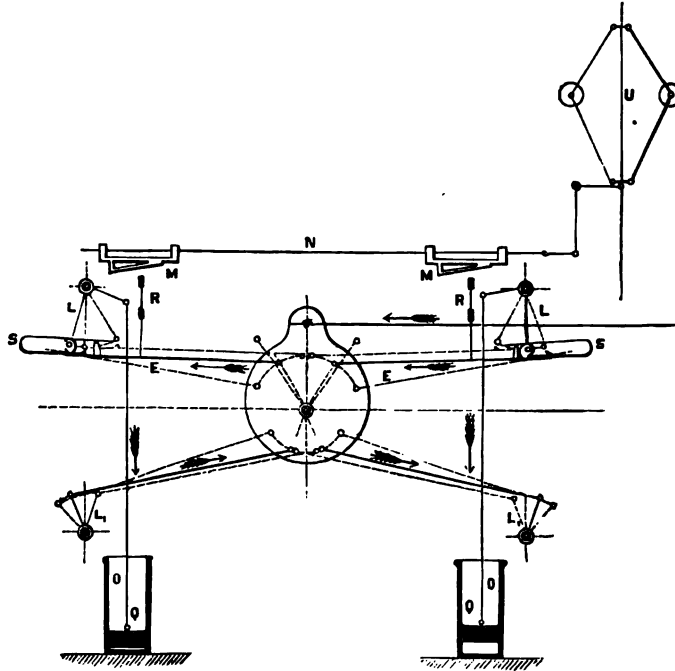
Fig. 404.—Corliss Valve-gear. Third Form.

contrary, the motion of the spring or weight by which it is closed is not arrested by the dashpot till after the valve is closed and the steam is cut off sharply. Whatever advantage, therefore, there is in minimizing wiredrawing, and ensuring a " square" cut-off, as exhibited on the indicator diagram, is on the side of the sliding valve.

In his second form, introduced in 1850, Corliss employed circular valves or slides, rotating within cylindrical seats. This is the form generally known as the Corliss valve. In his third form, designed in 1851 or 1852, his engines first became known in Europe. The design of this gear is shown diagrammatically in fig. 404. The rods of the steam-valves are held engaged with the levers L. L, by the springs S, S, and are thrown out of gear by the bars R, R, which rest on them, and are, at the right point of the stroke, pressed down upon them by contact with the inclined planes M, M on the horizontal bar N, the position of which is adjusted by the governor U.

When the levers L are released they are forced into their positions, cutting off the steam by the weights Q, Q, which fall in the dashpots O, O, in which they work air-tight. The escape of the air below the piston, in each dashpot, is regulated by means of an adjustable valve, so that the weight may fall without shock. The opening of the inlet valves is due to the pull of the rods E, E; and the closing of them is effected by the falling weights.

In 1858, Corliss designed a modification of his trip-gear, fig. 405. The sleeve N is pivoted on the end of the valve-lever L, and is traversed by a prolongation of the draw-rod E. To the rod E a fork BB is pinned at M, and the lower limb of the fork is sustained by a spring in contact with the sleeve N. A steel plate O is fixed on the end of the lower limb, by which, when in position, the sleeve is caught, and the lever is pulled by the draw-rod. The disengagement is effected by the pressure of a projecting pin or stud R, on a separate lever M′ connected by the rod N to the governor. As the lever L is pulled leftwards, the upper limb of the fork BB is depressed by the stud R, and

Fig. 405.—Corliss Gear. Fourth Form, as applied to a Harris-Corliss Engine.

so the lower limb is forced down out of touch of the sleeve, and the lever L is released, and pulled back by the weight acting through the rod P. This form of Corliss gear has been adopted by Mr. W. A. Harris, in engines known as Harris-Corliss engines, with one of which the tests already noticed, vol. i. page 515, were made.

INGLIS & SPENCER'S AUTOMATIC TRIP-GEAR.

Messrs. Inglis & Spencer patented and introduced, in 1863, a simplification of the Corliss system, so far as related to the liberating gear.[1] This is shown in side elevation in fig. 406, as applied to a small horizontal steam engine constructed by Messrs. Hick, Hargreaves, & Co. for the Royal Arsenal at Woolwich, from the designs of Mr. Wm. Inglis. The cylinder is 12 inches in diameter, with a stroke of 24 inches, and the engine makes 100 turns per minute. The cylinder is shown in section in figs. 407. The steam-valves A, A, are placed on the top of the cylinder, and the exhaust-valves B, B, at the bottom; and separate steam-pipes and exhaust-pipes lead to and from them, at each end of the cylinder. The steam-valves are closed by dashpots C, C, one to each valve, which pulls upon each valve-rod as it is drawn out. The liberating gear consists of a pair of side spring-clips D, D, which are released by the rocking of what may be designated a double-cam lever E, E, and then allow the steam-valve to be closed by the action of the spring. The liberating gear is similar to that which will be described in detail for the Saltaire engines,

[1] See Mr. Wm. Inglis' paper "On the Corliss Expansion Valve-gear for Stationary Engines," in the *Proceedings of the Institution of Mechanical Engineers*, 1868, page 177.

following. The valves are cylindrical on the face, being similar in action
to ordinary slide-valves, but working on a cylindrical face instead of a
flat face.   The face of the valve is a longitudinal segment of a cylinder,
having recesses on its inner side, which are occupied by the projecting
arms of the valve-spindle, by which the valve is moved in opposite direc-
tions alternately, in response to the alternating rotative movement of the
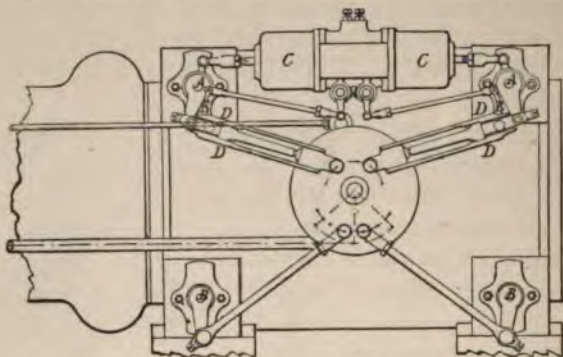
Fig. 406.   Scale 1/16th.
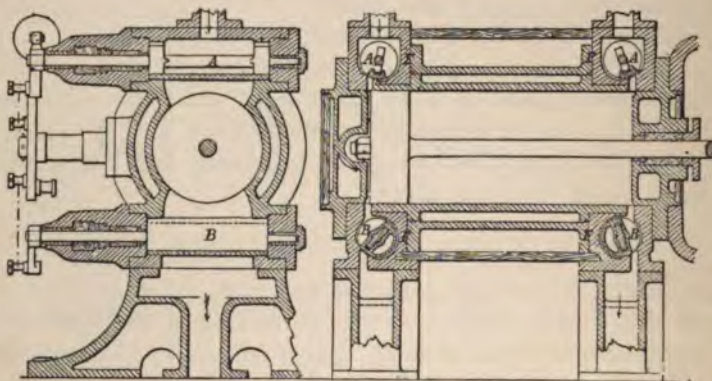
Figs. 407.   Scale 1/32d.
Inglis & Spencer's Automatic Trip-gear for Corliss Valves, Woolwich Arsenal.

spindle.   The valves move with very little friction from the pressure of the
steam, when the ports are open, and they are only pressed up to the valve-
faces of the valve-chests when the ports are closed.   Thus, the pull re-
quired to close the steam-valves is small, and is practically independent of
the pressure of the steam.

The cylinder is steam-jacketed on the case and on the ends.   The
cylinder and valve-chests are cast in four distinct pieces, with flanged
face-joints, to connect all together.   The cylinder and the steam-jacket
are two concentric castings, fitting one inside the other, with flanges FF
upon the jacket only; and by a separate casting at each end the valve-
chests above and below the cylinder are formed, with a ring connecting
the two valve-chests.   The end of the cylinder is fitted into this ring, and

the cylinder cover is fixed upon it—all the fitting surfaces being turned and bored. The separate castings are simple, and can be made independently of any degree of hardness. As a result of three months' working, the total average consumption of coal was 2½ pounds per indicator horse-power per hour, with a steam pressure of 45 lbs. per square inch.

The same kind of expansion gear has been applied to the vertical cylinders erected by Messrs. Hick, Hargreaves, & Co. at the Saltaire Works, according to the designs of Mr. Inglis. The engines are beam-engines coupled together, with 50-inch cylinders and 7-feet stroke, making 30 turns per minute. One of the cylinders is shown in elevation in fig. 408. The steam valves C are in front, and the exhaust-valves D are at the back of the cylinder; E, E, are the steam-passage and exhaust-passage. All the four valves are opened by the eccentric-rod T, acting on an oscillating disc U, to which the four valves are connected by rods. The exhaust-valves D are also closed by the same means, and are so worked without interruption. But the steam-valves C are released, and are closed, by an air-spring P. The sectional area of the steam-passage is ¹/₁₆th of that of the cylinder, with a total clearance of 2½ per cent of the net capacity of the cylinder. The exhaust-port has a sectional area ¹/₁₀th of that of the cylinder. The stop-valve G in the steam-passage is like the steam-valves, and is opened by a worm and

Fig. 408.—Inglis & Spencer's Corliss Valve-gear, at Saltaire. Scale 1/60th.

wheel to regulate the supply of steam; but it can be closed suddenly on an emergency by means of the lever-handle H keyed on the valve-spindle, and connected to the worm by a detent, which can be instantly disengaged, the worm-wheel being loose on the spindle. A small auxiliary conical stop-valve I, opened by a screw-handle, is employed for turning on the steam gradually at starting, to relieve the pressure on the main stop-valve G.

The construction of the liberating valve-rods in the Saltaire engines, introduced by Messrs. Inglis & Spencer, is shown in figs. 409, 410, and 411. The valve-rod is divided into two portions, one of which slides telescopically within the other at the cylindrical part A; and they are held together by the spring-clips B, which are fixed on one of the portions, and rest on corresponding shoulders C on the other portion of the valve-rod. The clips are released by the double-cam lever D, which rocks upon a centre-pin, and is shown in its two extreme positions in figs. 409 and 410. The outer end, K, of the arm of the lever being held by the rod L, shown in the

general view, fig. 408, the cam-lever is caused to rock during each stroke of the valve-rod, and the particular point of the stroke at which the cam-lever reaches its extreme position, and disengages the spring-clips, is determined by the position of the end K of the lever, which is comparatively stationary, though it is acted on directly by the governor, through the rod L. By this means, all the changes in position of the governor-balls produce corresponding changes, at the same time, in the position of the cam-lever and the cam-like projections. These act on the clips, forcing them apart, and causing their release to be earlier or later in the stroke according as the speed of the governor is greater or less than the correct rate:—thus regulating the engine by cutting off the steam earlier or later accordingly. The spring-clips B fall upon leather faces O, to prevent any blow in closing. The engaging edges of the clips and the shoulders are hardened steel faces let in, and readily renewable.

Fig. 409.   Fig. 410.   Fig. 411.
Inglis & Spencer's Corliss Valve-gear: Valve-rod, Saltaire.
Scale ⅙th.

The disengaging rods L are coupled together by a pair of toothed segments M, shown in fig. 408 and in fig. 412; and thus their simultaneous action is secured. The air-spring dashpot P for this gear, fig. 408, is shown enlarged in fig. 412, one-half in section. It consists of two cylinders, one within the other. The larger cylinder has a loose-fitting piston R, and the smaller cylinder a trunk piston S, fitted with metallic packing; the inner side of the trunk piston being in connection with the condenser. The piston, therefore, is constantly being pressed in by the atmosphere; and this forms the spring

Fig. 412.—Inglis & Spencer's Corliss Valve-gear:
Dashpot.   Scale 1/18th.

for quickly closing the steam-valve when liberated from the clip-rod. The larger piston R is coupled to the small one S, and acts as a dashpot to pre-

vent concussion in closing the steam-valve, as the air below the larger piston has to be driven out at the moment of closing the valve.

In the more recently constructed dashpots, helical steel springs are employed in addition to atmospheric pressure for closing the valves. Thus, equal or greater closing force may be employed with smaller dashpots.

The double-clip gear works satisfactorily, and is effective for speeds up to 120 turns per minute. Indicator diagrams from the Saltaire engines are shown in figs. 413, making 30 turns per minute. The consumption of fuel has been stated to be at the rate of 2½ pounds of coal per indicator horse-power per hour, including all coal used for getting up steam and banking fires.

MUSGRAVE'S AUTOMATIC SLIP-MOTIONS.

Slip-motion for Double-beat Stamp-valves.—This motion is illustrated by figs. 414, as applied to a high-pressure or M'Naught cylinder of a beam steam engine, 3 feet in diameter, which is placed at half-way between the main centre of the beam and the crank-shaft, and has

Figs. 413.—Indicator Diagrams from Saltaire Engine, fitted with Inglis & Spencer's Corliss Valve-gear.

half the stroke of the ordinary cylinder, into which the steam is expanded from the high-pressure cylinder. This cylinder is cast with a round frame or stand of suitable height, as a base, on which it is raised up out of the way of the crank and connecting-rod.

The cylinder is fitted with double-beat valves, having discs 7 inches and 6½ inches in diameter, with a lift of 1 inch, for steam and for exhaust, at the top and the bottom of the cylinder. Four 2-inch vertical valve-rods, in front of the cylinder, are lifted by four tappets fixed on a horizontal transverse shaft at the base of the cylinder, making one revolution for each double stroke of the piston. The valve-rods are in pairs, one pair to each end of the cylinder, connected with the valves for the steam supply and the exhaust. The steam-valves are shown in section; and they and their rods are to the right in the front view, whilst the exhaust-valves and their rods are to the left. The rods, lifted by the tappets, drop, when released, by their own weight. Each steam-valve rod is in two parts, of which the lower part is square, and slides within a rectangular box or case which terminates the upper part of the rod. The square end of the lower part is bevelled, and is fitted with a steel finger, which is pivoted to the lower end of the bevel surface, and points upwards. A bent lever, or elbow-lever, has its fulcrum in the upper part of the box, to which it is pinned. The lever has a short arm pointing downwards; and a longer arm pointing

horizontally, connected, by a rod leading upwards, with the governor. As the upper part of the rod rises and falls, the bent lever, held by the governor-rod, vibrates on its fulcrum, with the result that the shorter arm
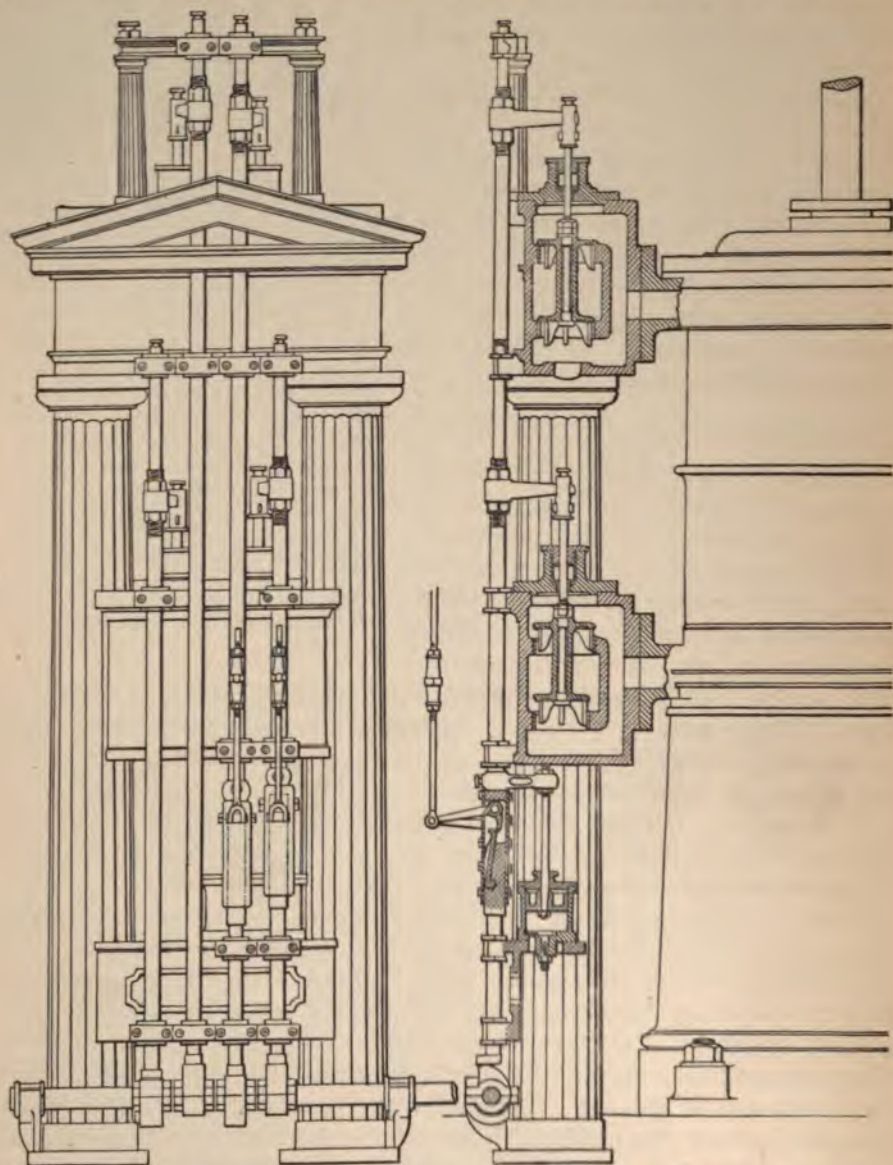
Figs. 414.—John Musgrave & Sons: Slip-motion for Double-beat Stamp Valves. Scale 1/24th.

oscillates horizontally. When the rod is at the lower end of its lift, the shorter arm is directly over the end of the finger, and it, with the upper part of the rod, and the steam-valve, are lifted by the finger when the lower part of the rod is raised by the action of the tappet. The upper

and lower parts are, for the occasion, one rod; and they act as such until
the shorter arm, moved, in consequence of the upward motion, towards the back of the box, slips over the end of the finger, when the upper part of the valve-rod drops, and the valve falls to its seat. Following this movement, the lower part of the valve-rod, set free by the revolution of the tappet, also drops. The finger, freed from the contact of the short arm, is, by the action of a spring, laid back on the bevelled surface to which it is pivoted, resuming its position under the shorter arm of the lever, in readiness for the next lift by the tappet. The position of the elbow lever is varied, according to the load on the engine, by the governor, in the usual manner; and so variable admission and expansion are obtained. A dashpot, with an adjustable outlet air-valve, is applied, having its piston attached to

Figs. 415.—John Musgrave & Sons: Slip-motion applied to a Horizontal Cylinder having Corliss Valves.

the upper part of the valve-rod, so that the blow of the valves on the seating may be reduced to a minimum.

Slip-motion applied to a Horizontal Cylinder with Corliss Valves.—The two exhaust-valves, at the lower side of the cylinder, figs. 415, are linked together, and are worked by an eccentric in the usual manner. The two steam-valves, at the upper side of the cylinder, are worked from a rocking lever pivoted to the centre of it. The lower arm of the lever receives the reciprocating motion of a special eccentric, and from the upper arm the levers of the steam-valves are worked by means of valve-rods, adjustable in length. The upper arms of the valve-levers are in connection with two pistons, one for each arm, in a double-ended dashpot, containing a helical steel spring, lodged between the pistons. The recoil of the springs is softened by an air-cushion inclosed behind each piston, the quantity of
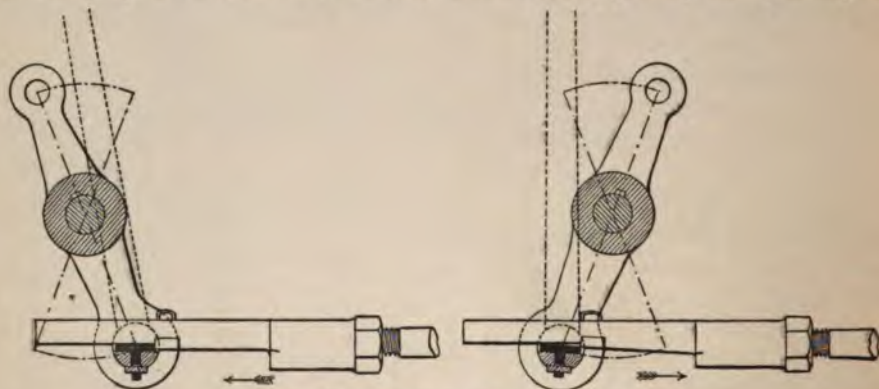
Figs. 416.—Detail of Trip-catches. Scale 1/6th.

which is regulated by escape-valves, which are adjustable. The ends of the valve-rods work in the forks of the valve-levers. They are flat, and each rod-end is notched on the under side to receive a wearing piece of steel which projects downwards as a catch for pushing against a T-shaped steel piece lodged in a centre or pin, carried loose in the eyes of the fork, as shown in detail, figs. 416. On the end of this pin an arm is fixed, the upper end of which is linked to one end of a lever above the dashpot, under the control of the governor. As the valve-lever vibrates, the position and angle of the upright arm and of the T-shaped piece are varied, so that when the valve is shut the flat part of the T piece is level, and is in full contact with the wearing piece notched into the valve-rod, in readiness for pushing over the valve-lever and opening the valve. When the lever is pushed over, the angle of the upright arm on the centre or pin is altered, and the T piece is tilted so as to slip from contact with the wearing piece on the valve-rod. The valve, thus released, is closed by the spring in the dashpot, the time of release and of closure of the valve being regulated by the governor according to the load on the engine.

Slip-motion applied to a Horizontal Cylinder with Corliss Valves at the bottom, worked by Tappets.—In this gearing, fig. 417, applied to a steam cylinder 25 inches in diameter, with 6½-inch Corliss valves, placed side by side at each end of the cylinder, the valves are worked by front or

lifting rods, 1¾ inches in diameter, raised by tappets fixed on a transverse shaft near the base; the shaft being driven by spur-wheels from a shaft driven by the main shaft. From the same shaft the governor is driven with bevel gear. On a pin fixed into the end of an arm keyed on each
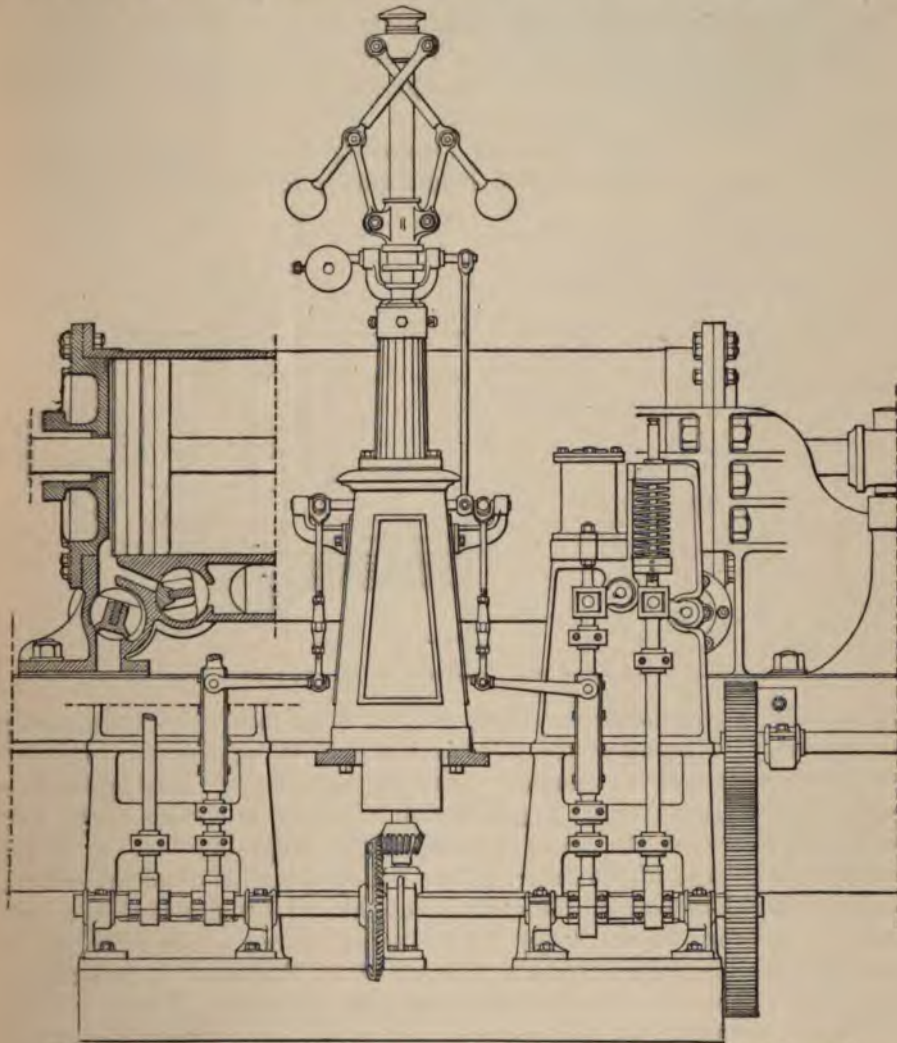
Fig. 417.—John Musgrave & Sons:—Slip-motion applied to a Horizontal Cylinder with Corliss Valves at the bottom, worked by Tappets. Scale 1/24th.

valve-spindle, a square block is carried, which works in a rectangular opening in the valve-rod: the opening being wider than the block to provide freedom for vibration laterally as the rods rise and fall. The steam-valve rod is in two parts, having a sliding box with automatic slip-motion, similar to what has already been described for double-beat valves. When the rod is slipped, its descent, and consequently also the closing

of the valve, are accelerated by the action of a helical spring within a
small air-cylinder upon a piston fixed to the upper end of the rod. The
drop of the exhaust-valve rod, as it is freed from the tappet, is also
accelerated by the action of a helical spring. The steam-valve, it may
be noted, opens and closes by a single edge; whilst the exhaust-valve
opens and closes by two edges, equivalent to a double-port. For this
purpose the working face of the exhaust-valve is hollowed out at the
middle; so providing the second passage-way for the exhaust steam when
the valve rotates.

Corliss Valves with Musgrave's Traversing Motion.—Corliss valves are
by this motion gradually shifted longitudinally to the right and the left
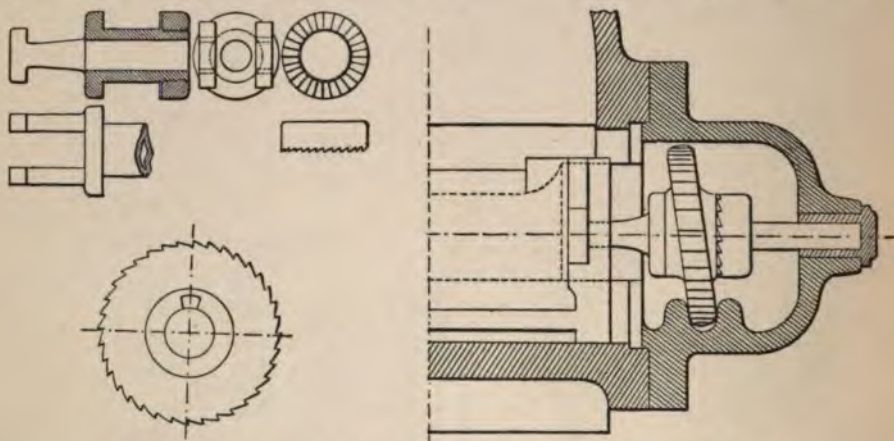
Figs. 418.—John Musgrave & Sons: Corliss Valve with Traversing Motion. Scale 1/8th.

alternately, as represented by figs. 418, for a 40-inch cylinder, in order
to prevent the cutting of the valve into ridges by wear of the face, and
to ensure a smooth and uniform working surface. A sloping ratchet-
wheel, or "eccentric ring," $7\frac{1}{2}$ inches in diameter, is carried by a loose
collar or sleeve on the valve spindle, and is kept in place by a nut
screwed on the end of the collar. Thus the combination of ratchet-wheel,
collar, and nut is loose on the valve. But the collar is provided with two
arms of the form of the letter **T,** as in the figures, which reach along
and embrace the flat sides of the valve spindle. The collar is thus caused
to rotate reciprocally with the valve, and with it the nut. The movement
is likewise communicated, in one direction, as the valve opens the port, to
the ratchet-wheel, by means of a detent lodged in a cavity of the ratchet-
wheel, which is pressed outwards by a small helical spring upon the inner
face of the nut, which is notched to receive the detent. The ratchet-
wheel, having thus been turned round by the nut, is prevented from return-
ing with the next oscillation, when the valve closes the port, by a spring
detent or catch fastened to the casing. In this way the ratchet-wheel is
gradually revolved in one direction on the spindle; and, working in a slot
between the ledges at the bottom of the casing, it necessarily, by its

obliquity, induces a reciprocating traversing movement of the valve on its
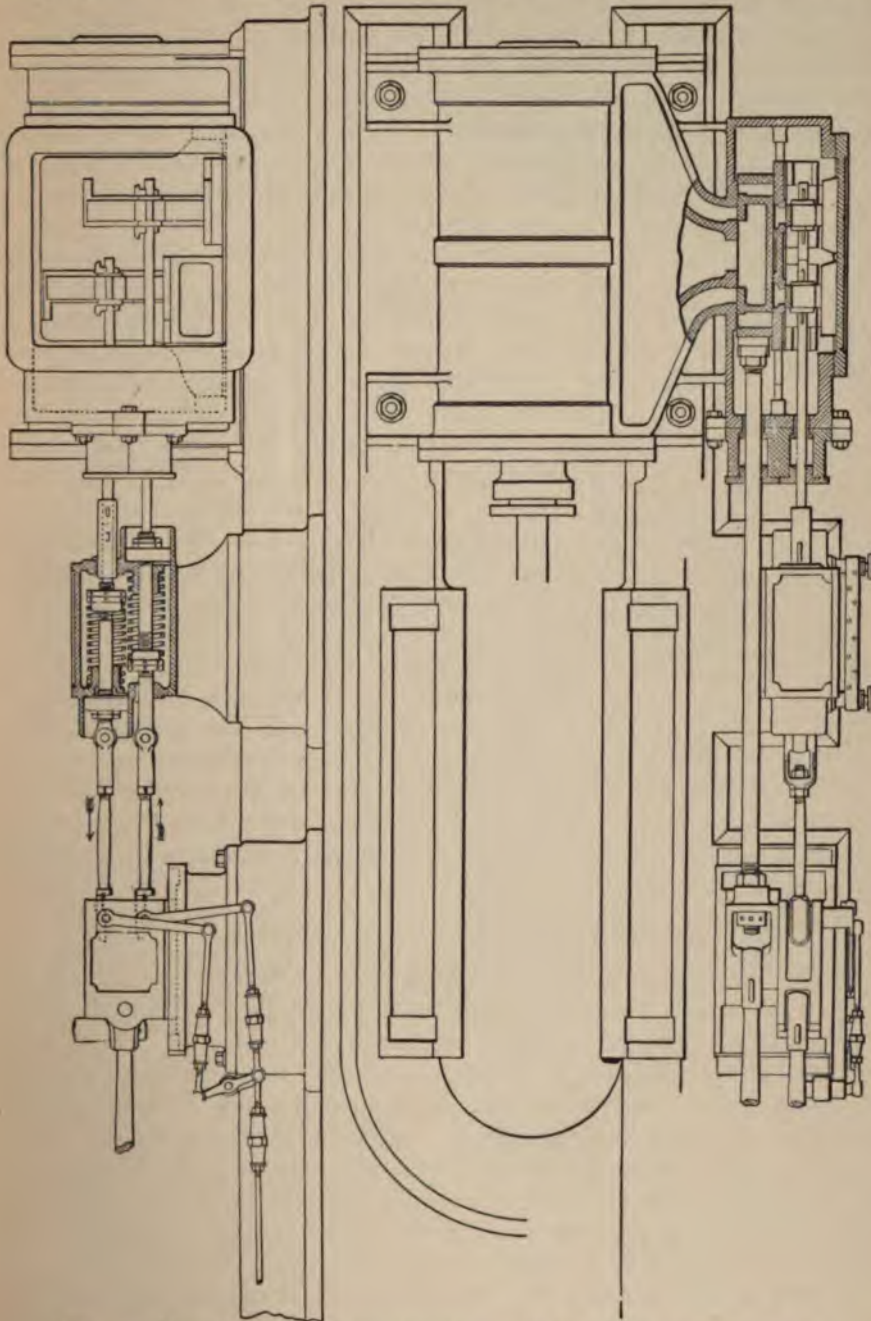
Figs. 419.—John Musgrave & Sons: Slide-valve and Automatic Slip-motion, fitted on a Horizontal Cylinder.   Scale 1/24th.

axis.   The valve is alternately pushed and pulled by means of the **T** heads

already described, which are lodged in a recess formed for them at the end of the valve.

Slide-valve and Automatic Slip-motion, fitted on a Horizontal Cylinder.— In this case, the cylinder, figs. 419, 22 inches in diameter, has the usual three ports. These are traversed by a slide-valve having an exhaust-cavity, and at each end a steam-port. Over this valve is placed a plate having steam-ports corresponding to those in the cylinder, held in place by the pressure of the steam. The two slip-motion expansion-valves work on this plate. A few holes are drilled through the plate to admit steam between it and the main valve, inside the pan-elled facings; and thus beneficially to counterbalance the little extra frictional resistance which the plate entails. Valves of this type have been working on high-pressure steam cylinders of diameters up to 35 inches. It is stated that they wear well, and give no trouble, many having been at work over eight years, and the valve-faces continuing in good order. The slip-motion, shown in detail, figs. 420, is the same in principle as that for the Corliss valves, figs. 416, with the difference that the T pieces are held in a slide-block, and they push and pull the horizontal valve-rods; whereas, in the Corliss motion, the horizontal rod pushes the T piece which is held between the limbs of the forked lever on the spindle of the steam-valve. The point of cut-off is regulated by the governor in the same manner.

Figs. 420.—Detail of Slip-motion. Scale ⅙th.

GALLOWAYS' AUTOMATIC SLIP-GEAR.

The slip-gear employed in the horizontal twin compound steam engines of Messrs. Galloways, illustrated by fig. 421, is applied to the first cylinder. The slide-valves are plain flat-plates, of which there are two for the admission of steam to each end of the cylinder, through short and direct passages, worked from a small crank on a weigh-shaft driven by the main crank-pin, through trip-gear under the control of the governor. The valve-rods, of which there is one to each cut-off valve, are each in two parts working in a guide, within which they alternately engage and disengage by the medium of small steel plates or catch-pieces. Of these, one is fixed on the end of one part of the valve-rod—the part next to the cylinder; and the other is fixed on one end of a bell-crank trigger lever pinned to the other part of the valve-rod. By the alternate lowering and raising of the end of the lever in consequence of the action of the eccentric, and the reciprocations of the valve-rod, the

plates are alternately engaged and disengaged. When the plates are engaged, the valve-rod and valve are pushed towards the left; after proceeding in contact for a part of the travel, the lever heels over, its catch-piece is raised and so disengaged, and the valve-rod and valve are free, to be quickly reversed and pushed outwards by the pressure of the steam within the valve-chest, and brought to rest without shock by a dashpot. To provide sufficient area for the outward pressure, each valve-rod is enlarged at the stuffing-box, and works as a plunger through it. The
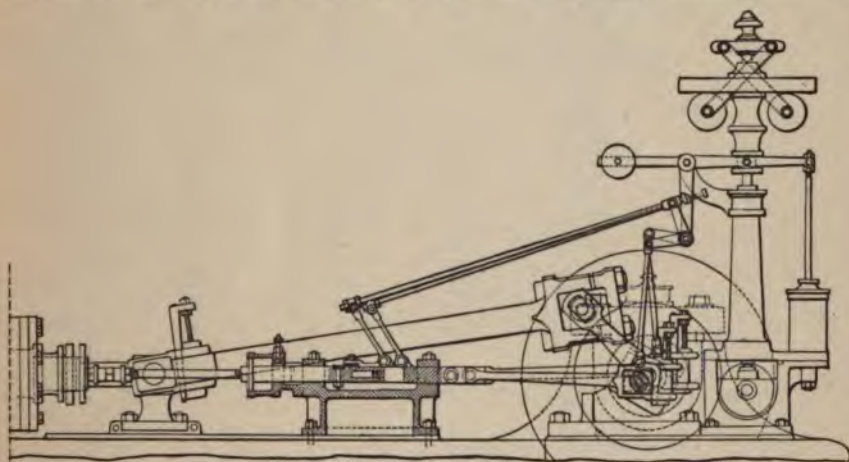
Fig. 421.—Messrs. Galloway: Automatic Slip-gear for Horizontal Engines.

sectional area of the plunger is the measure of the thrusting-out pressure. The trigger levers are worked through other bell-crank levers which are centred on a movable shaft suspended from a counterbalanced lever connected with the governor, and worked by vertical links from the eccentric-straps. It thus appears that the motion of the trigger levers is a compound of two movements, impressed respectively by the valve-rods horizontally, and the eccentric-straps vertically. By the vertical movements of the governor, the position of the fulcrum of the second bell-crank levers is shifted, and a variable cut-off is so effected.

WOOD'S AUTOMATIC SLIP-MOTION APPLIED TO CORLISS VALVES.

A direct and compact form of slip-gear, designed and introduced by Messrs. John and Edward Wood, Bolton, is illustrated by figs. 422 and 423, as applied to a horizontal mill engine, having a 29-inch cylinder. There are four Corliss valves at the lower side of the cylinder, in a horizontal line. They are in two pairs, one pair at each end of the cylinder, the outermost of each pair being the main valve for admitting and exhausting the steam from one end of the cylinder; and the inner is an expansion-valve for varying the cut-off, by means of slip-gear. The valves are on spindles, on the outer ends of which arms and levers are fixed, to receive and transmit the reciprocating motion of two
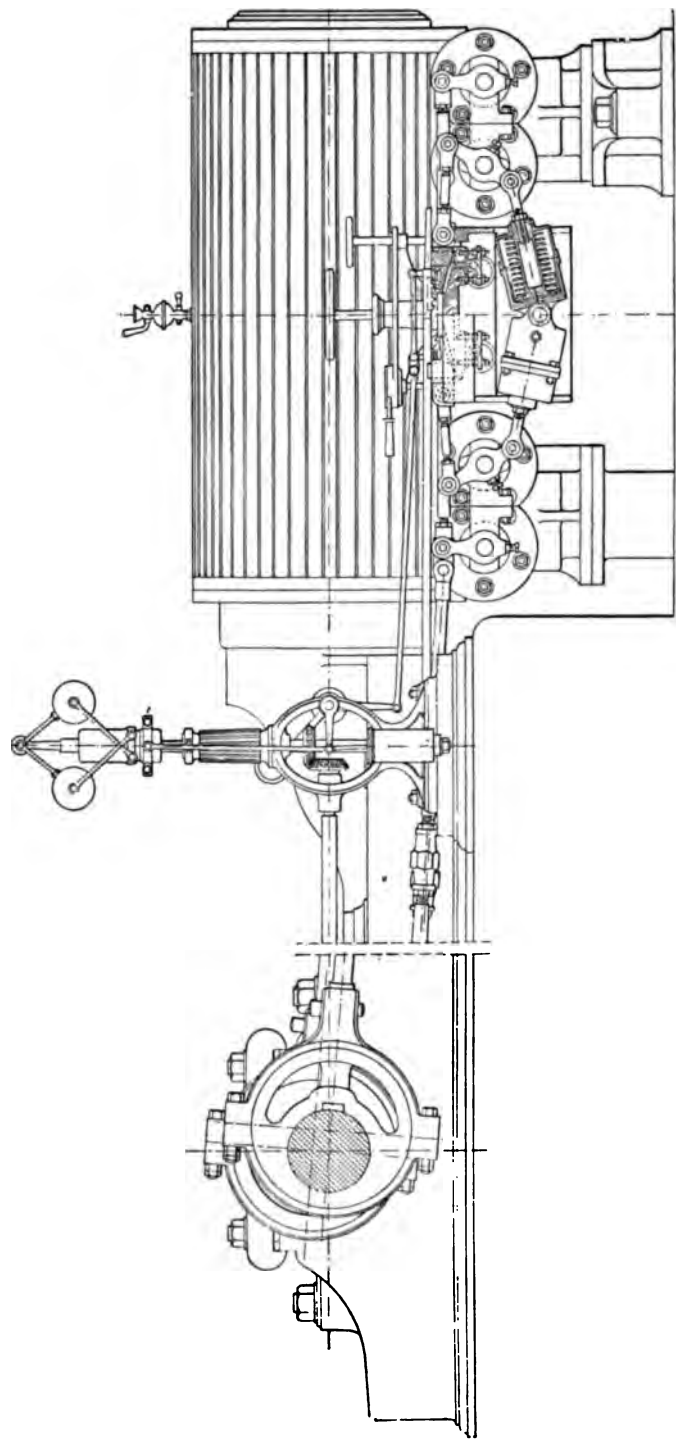
Fig. 422.—J. & E. Wood: Automatic Slip-motion, for Horizontal Cylinder having Corliss Valves. Side Elevation. Scale 1/28th.
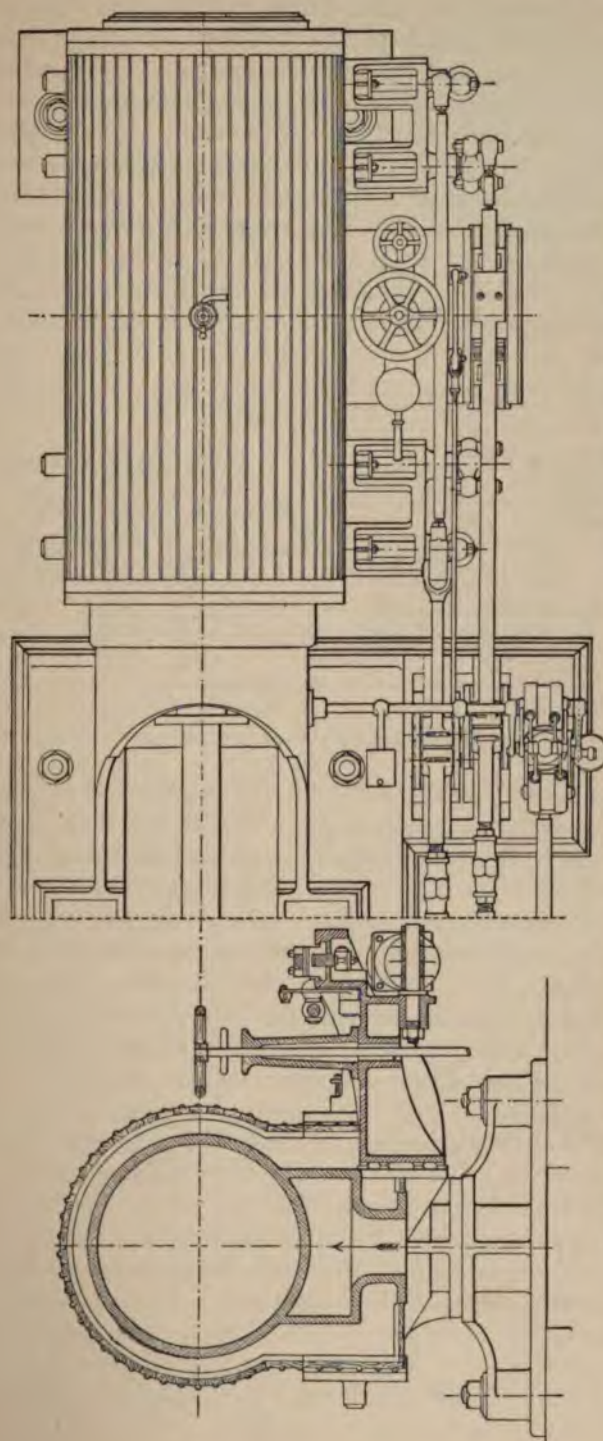
Fig. 423.—J. & E. Wood: Automatic Slip-motion, for Horizontal Cylinder having Corliss Valves. Cross Section and Plan. Scale 1/28th.

eccentrics on the main shaft. The inner eccentric, having 5¼ inches of throw, gives a constant motion to the two main valves, the arms of which are connected by a rod; and the outer eccentric, having 6 inches of throw, gives motion to the expansion-valves. The expansion eccentric-rod carries a steel plate fixed to its lower side, near the end of it, on which there are two pairs of teeth. The forward pair of teeth engages with corresponding teeth on a steel plate fixed on a sliding catch-block, which is linked to the upper end of the fore expansion-valve lever; and the back pair, similarly, engage with corresponding teeth on a sliding catch-block, linked to the back expansion-valve lever, as shown in detail, fig. 424. The drawing shows the driving or eccentric rod at one end of its stroke in gear with the
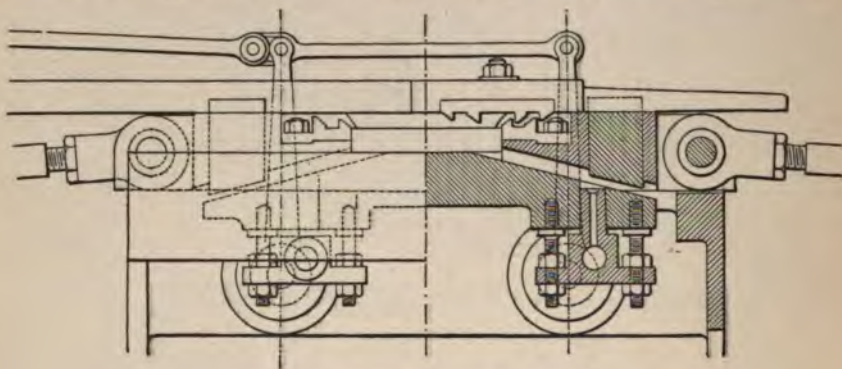
Fig. 424.—Detail of Slip-movement. Scale ⅙th

back catch-block; and, as the rod with the catch-block in gear is pulled forward, the valve begins to open the port; at the same time, a square trigger-block which slides vertically through and is carried by the catch-block, is brought into contact with a fixed piece formed with an inclined plane, on which the trigger-block rises. In rising, the trigger-block lifts the eccentric-rod, which rests upon it, and so frees the teeth which are in gear, and liberates the valve-lever. The valve-lever, thus liberated, is pulled over by a spring in a dashpot or buffer-cylinder, connected to the lower end of the lever, and so the valve is closed. The same action takes place for the fore expansion-valve, on the return of the eccentric-rod.

The variation of the expansion, by the action of the governor, is effected by vertically adjusting the level of the two inclined bearing pieces by which the trigger-blocks are lifted, so that the trigger-blocks may be raised earlier or later, and the teeth liberated accordingly, for the shutting off of the steam. For this purpose the inclined pieces are centred each on a short arm of a lever, of which the longer arm is connected with the governor. As the governor rises and falls, the levers are pulled or pushed, the inclined pieces are raised or lowered, the teeth are liberated earlier or later, and the steam is cut off earlier or later. The period of admission may thus be varied from 0 to 75 per cent of the stroke.

Only one valve at each end of the cylinder, as before stated, is employed for admitting and discharging steam. The reciprocations are constant.

The eccentric-rods are not continuous. They are each divided into two parts, the ends of which are pivoted to slides, which are supported on guides. The valve arms and levers, as well as the trigger-blocks, are thus relieved of a great proportion of the weight of the rods.

A compound steam engine, fitted with the trip-gear, was erected at the Gordon Mills, Bombay. The cylinders are 36 inches and 60 inches in diameter, with a stroke of 6 feet, having piston-areas as 1 to 2.78. In one case the speed was 50½ revolutions per minute, with a working pressure of 88 lbs. per square inch in the boiler. The maximum pressure in the first cylinder during admission was 77 lbs. and 78½ lbs. per square inch above the atmospheric line. The steam was cut off in the first cylinder at about one-fourth of the stroke, making a total nominal expansion of 11.12 times. The back pressure in the first cylinder varied from 7 lbs. or 8 lbs. to 12 lbs. or 12½ lbs. per square inch, the maximum pressure taking place at half-stroke. In the second cylinder the maximum pressure of admission was 9½ lbs. and 10 lbs. per square inch above the atmosphere; and the degree of vacuum was about 12¼ lbs. per square inch. The vacuum-gauge showed 25½ inches of mercury. The average effective pressures and horse-powers were as follows:—

	Average Pressure per sq. inch.	Horse-power.
1st cylinder	28.25 lbs.	527.9 I.H.P.
2d do.	11.13 „	577.6 „
Total power		1105.5 „

The coal consumed per day of 12 hours was 10¼ tons, equivalent to 1.73 pounds per indicator horse-power per hour. This quantity included the coal required for the heating of the mill.

A horizontal tandem compound steam engine constructed for Messrs. Ainsworth Brothers & Co., Bolton, has two cylinders 29 inches and 45 inches in diameter, with a stroke of 6 feet; having piston-areas as 1 to 2.41. It has indicated an average of 720 horse-power, consuming 38 tons 12 cwts. of ordinary Lancashire slack per week of 56½ hours, or 2.12 pounds per indicator horse-power per hour, inclusive of coal required for the heating of the mill and offices, day and night, including Sundays. The engine makes 51 turns, or 612 feet of piston, per minute.

CORREY'S EXPANSION GEAR, WITH TRIP-MOTION.

Correy's system of trigger gear, applied to vertical compound engines, is illustrated by figs. 425.[1] The ordinary arrangement of valve-chests for Woolf engines is retained. The steam comes direct from the boiler into the jacket surrounding the two cylinders, and it passes thence by a starting-

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[1] See a paper "On Vertical Compound Engines fitted with Correy's Variable Expansion Gear," by Mr. Thomas Powell, in the *Proceedings of the Institution of Mechanical Engineers*, June, 1878, page 504.

valve to the valve chest of the first cylinder.   The main slide-valve is
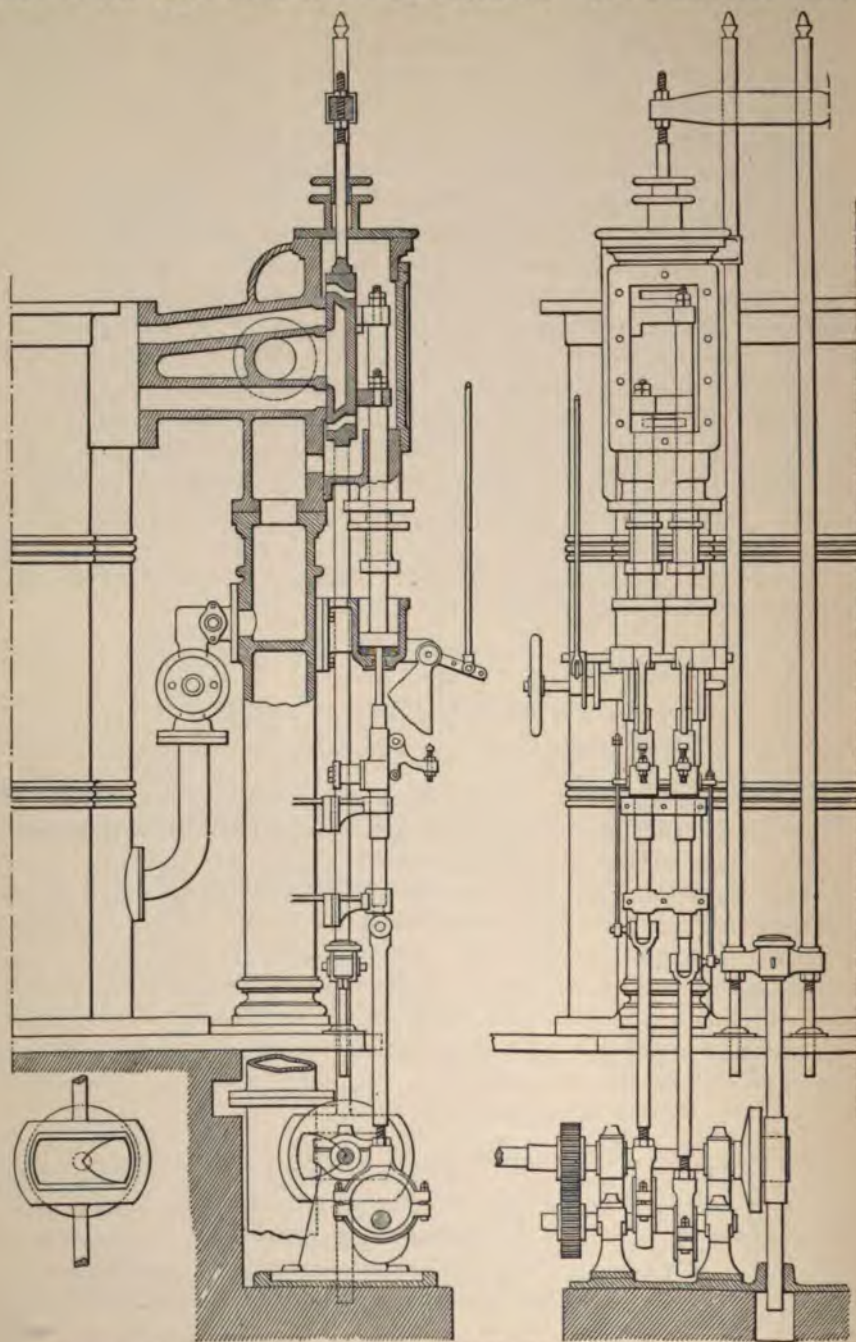
Figs. 425.—Correy's Expansion-gear, with Trip-motion, applied to a Vertical Cylinder.   Scale 1/20th.

double-ported, and admits steam for from 60 per cent to 90 per cent of the

stroke, according to the load. It is worked by a triangular eccentric, shown separately in figs. 425. Two expansion cut-off valves work on the back of the main valve. They are fixed on two separate vertical rods, which work through stuffing-boxes. The diameter of the rods is calculated so that the pressure of the steam on the upper end of each rod, plus the weight of the rod, may be greater than the frictional resistance of the valves and of the packing in the stuffing-boxes. By this means the slide-rods, with the slides, fall as soon as they are liberated, and the employment of springs or of counterweights for enforcing their descent is rendered un-

necessary. The rods are each fitted with a piston, which plays in a dashpot fitted with an india-rubber disc at the bottom, and prevents a blow. The rods are each in two parts, of which the lower part slides within the other, with which it is alternately engaged and disengaged by means of trip-gear. The rods are moved by two eccentrics keyed on the motion-shaft or on a small special shaft which is geared to the main shaft. The trip-gear is shown in sectional detail, fig. 426. The upper part of the valve-rod is socketed to receive the lower part. The upper end of the lower part is, for a short length, reduced in the latter, eccentrically, so as to form a crescent-shaped shoulder, of hardened steel, at one side of the rod. It is embraced by a sliding block, also of hardened steel, which fits and is

Fig. 426.—Detail of Correy's Slip-motion. Scale 1/8th.

movable transversely within a square opening in the upper part of the rod. By the alternate horizontal movement of the block—inwardly by the trip-gear, and outwardly by the pressure of a reacting spring, the shoulder is alternately released from and engaged by the sliding block. When the shoulder is freed, the upper part of the valve-rod falls, and the valve is closed. When the lower part of the rod is pulled down by the eccentric, the block is pushed over the shoulder and unites the upper and lower parts of the valve-rod for the upward stroke, when the valve is opened. The regulation of the cut-off by the governor is effected by means of a bell-crank lever pivoted to the socket of the upper part of the valve-rod, of which one end is pinned to the sliding block, and the other end is fitted with an upright adjustable knife-edge, which is brought into contact with a cast-iron cam in the course of the ascent of the valve-rod. The bell-crank, in consequence, is turned on its pivot, and the lower arm is moved horizontally and pushes inwards the sliding block, so freeing the shoulder and breaking the connection of the upper and lower parts of the valve-rod. The two cams, one for each expansion valve-rod, are keyed on a small

horizontal shaft which is connected to and moved by the governor. The cams are finely notched to give proper bearing for the knife-edge studs. They are so formed as to vary the lift of the knife-edge before it touches them, under the control of the governor, and so to vary the cut-off.

The position of the cams, shown in the figures, indicates the maximum opening of the governor-balls, and the maximum speed. In this position the knife-edges come into contact with the cams when the crank is at the dead-point. The impact of the knife-edge on the cam is very feeble, as its only duty is to move the block off the shoulder. Besides, the action, in all positions of the cam, has its vertical component passing through the centre of the cam-shaft. As, therefore, the governor has no resistance to overcome, it has great freedom of motion; and to neutralize the oscillation to which it is liable, a small piston connected with the sleeve of the governor plays in a cylinder filled with oil.

Mr. Powell gives the results of a trial of the Woolf engine, erected in 1876, at the factory of Messrs. Waddington, Sons, & Co., with
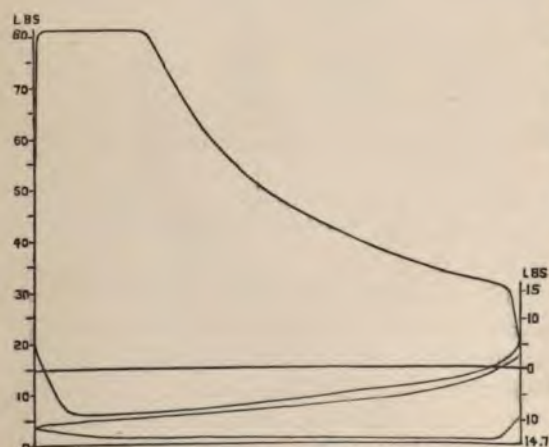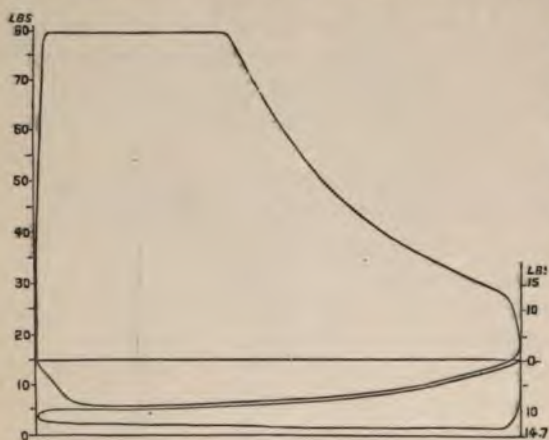
Figs. 427.—Correy's Woolf Steam Engine: Indicator Diagrams.

Correy's expansion gear. The first cylinder was $11^{15}/_{16}$ inches in diameter, or 253.1 square inches in area, with a stroke of 5 feet 1.92 inches; the second cylinder was nearly 37 inches in diameter, or 1073.4 square inches in area, with a stroke of 7 feet 0.84 inch. The capacities of the cylinders were in the ratio of 1 to 5.81. The speed was 24.5 revolutions, or 232.4 feet of the first piston, or 318.2 feet of the second piston, per minute. Indicator diagrams, figs. 427, were taken simultaneously from the four faces of the pistons. The effective pressure in the boiler was 67.3 lbs. per square inch. The total initial pressures in the first cylinder were $81\frac{1}{2}$ lbs. and 80 lbs. per square inch. The steam was cut off at 23 per cent and 39 per cent of the

stroke; showing a mean nominal expansion-ratio of 1 to 3.23 in the first cylinder, and of 1 to $(3.23 \times 5.81 =)$ 18.77 in both cylinders combined. During the trial, which lasted 13.65 hours, the average effective pressures were:—

	Lbs. per Square Inch.			Lbs. per Square Inch.
1st cylinder, top.........	46.595	2d cylinder, top.........	5.774
Do. bottom....	42.811	Do. bottom....	5.348
Mean.........	44.953	Mean.........	5.561

The products of these mean pressures respectively by the areas and by the strokes are as 1 to .72, representing the proportions of work done per stroke. The average indicator power was 135.8 horse-power, of which 78.9 horse-power was contributed by the first cylinder, and 56.9 horse-power by the second cylinder.

The water consumed by the engine per hour was 2129.8 pounds, or 15.7 lbs. per indicator horse-power per hour. But 267.2 pounds of steam per hour was condensed in the jacket, and returned to the boiler; parting with heat to the cylinder equivalent to that of 203.06 pounds of steam.[1] The total consumption of heat per hour is therefore to be taken as that of $(2129.8 + 203.06 =)$ 2333 pounds of steam, or 17.1 pounds per indicator horse-power.

TURNBULL'S AUTOMATIC SLIP CUT-OFF VALVE-GEAR.

The steam is cut off by two separate expansion grid-valves, one for each end of the cylinder, driven by slip-gear consisting of a revolving helicoidal cam, with the surface of which two slide-bars, in connection with the expansion-valves, are maintained in contact. As the cam revolves, the slide-bars slip over the helical edge alternately, and the steam is cut off.

An example of the valve-gear applied to an 18-inch horizontal cylinder is illustrated by figs. 428. A valve-chest is provided for each end of the cylinder, with a short steam-passage, and a double-faced slide-valve, which is reciprocated horizontally by an eccentric. It contains an exhaust cavity, and a through steam-passage, which is inclined towards the outer face, where it terminates as a grid of eleven ports or openings with horizontal bars. The cut-off valve is a corresponding flat grid, which slides vertically on the grid-face of the valve; and opens or closes the openings simultaneously. The vertical shut-off movement of each valve is derived from a spring in a dashpot, fixed on a vertical spindle which seizes the valve by two horizontal flanges cast on back of it. The flanges are, in fact, extensions outwards of two of the bars of the valve, and they are caught between two clutches which are cottered on the spindle. The clutches have plain faces, and though they effect the vertical reciprocation of the

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[1] Mr. Powell explains that 267.2 pounds of water at 314°.8 F., the temperature of the steam, contains as steam 314,724.7 units of heat; that the water returned to the boilers had retained 75,567.2 units; and that the heat remaining in the jacket was $(314,724.7 - 75,567.2 =)$ 239,157.5 units, the equivalent weight of which as steam is 203.06 pounds.

valve, they leave it free to move horizontally with the main valve, on which it is fitted with dovetail ledges.

The upper part of each expansion-valve spindle is slotted to receive the horizontal arm of a bell-crank lever, the other arm of which engages in the outer end of the horizontal slide-bar which is maintained in contact
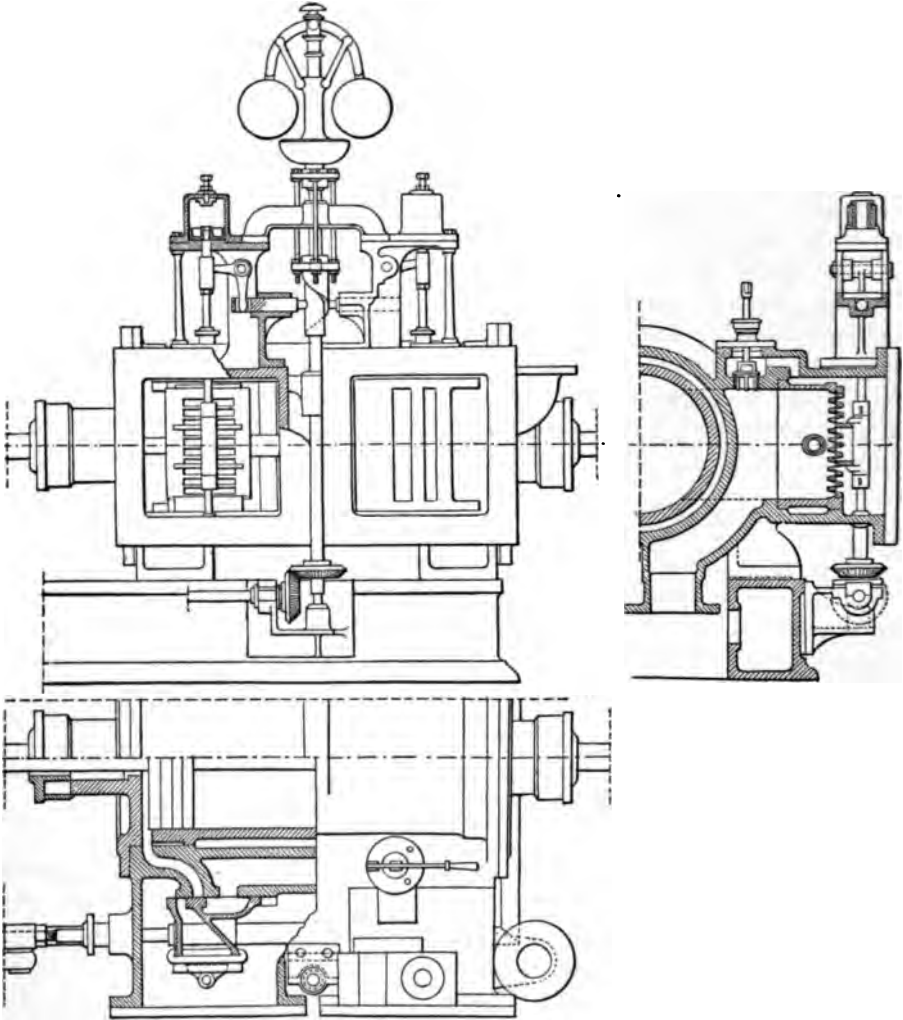
Figs. 428.—Turnbull's Automatic Slip Cut-off Valve-gear, on a Horizontal Cylinder.   Scale 1/24th.

with the cam.   The contact is maintained by the pressure of the spring in the dashpot, exerted through the bell-crank lever.   When the slide-bar slips over the raised edge of the cam, it is immediately pressed home upon the lower surface of the cam, and, simultaneously, the expansion-valve is forced downwards, shutting off the steam.   To soften the blow of the spring, an atmospheric piston plays in the dashpot and receives the pressure.

As the cam continues revolving, the slide-bar is pushed back by the inclined surface of the cam, lifting the spring, and opening the expansion-valve. This action takes place alternately for both ends of the cylinder.

The period of admission is controlled by the governor, which is fixed on the same spindle that carries the cam, and is connected to the cam by four rods with nuts. The spindle is driven through mitre-gear from the main shaft, and as the governor rises and falls, the cam rises and falls likewise, and so varies its relative position with the sliding-bars for the cut-off.

As the steam is admitted and shut off through a valve of eleven ports, it is readily understood that the pressure

Fig. 429.—Indicator Diagrams with Turnbull's Slip-gear.

is maintained in the cylinder undiminished until the steam is cut off. The sample indicator diagrams, fig. 429, exemplify this action, and show a pressure of 35½ lbs. per square inch above the atmospheric line, which is only half a pound less pressure than that in the boiler—36 lbs.

CHAPTER V.—GOVERNORS.

The centrifugal force of a governor-ball may be calculated by means of the formulas (3) to (6), page 86, of which (6) is here produced.

$$c = .0000283 \ wrn^2 \dots\dots\dots\dots\dots\dots (1)$$

c = centrifugal force, in pounds.
w = weight of the ball, in pounds.
r = radius of revolution, measured to the centre of the ball, in inches.
n = revolutions per minute.

The cone of revolution of a governor has its base in the horizontal plane in which the centres of gravity of the balls circulate. The number of revolutions per minute is equal to the number of double vibrations of a pendulum, within a small arc, of which the length is equal to the height of the cone; and is inversely proportional to the square root of this height. Conversely, the height of the cone is inversely as the square of the number of revolutions per minute. The seconds pendulum in the latitude of London is 39.1393 inches in length, and makes 60 beats per minute. For any other number of beats or of vibrations, N, the length is equal to $\frac{39.1393 \times 60^2}{N^2} = \frac{140,901}{N^2}$. The height of a conical governor making n revolutions, equivalent to half the number of beats of a pendulum of the same length, is expressed by the following formula (2), in which one-fourth of

the numerator in the above fraction is adopted, that is, the numerator is multiplied by $(\frac{1}{2})^2$:—

$$h = \frac{35225}{n^2} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

h = height of the cone, in inches.
n = number of revolutions per minute.

Conversely,

$$n = \sqrt{\frac{35225}{h}} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3)$$

or,

$$n = 188 \sqrt{h} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4)$$

That the governor may be efficient it must be prompt to follow and check variations of speed. The original governor of Watt, fig. 430, is very

Fig. 430.—Watt's Governor.

simple. The dot-lines indicate its range of action —raising or lowering the point of communication with the throttle-valve at the top. The arms are hinged on a pin common to both in the axis of the spindle, and it is apparent that the height of the cone is reduced as the balls are spread, and necessarily also the speed, since the spread of the arms is dependent solely on the velocity of rotation. It is easily understood, therefore, that a governor may not be active enough or sufficiently prompt to check variations of speed before they become very considerable—incurring constant fluctuations of speed, in consequence of the efforts of the governor to overtake the engine, occasionally overrunning it.

A short, compact, and commodious form of governor, fig. 431, is very
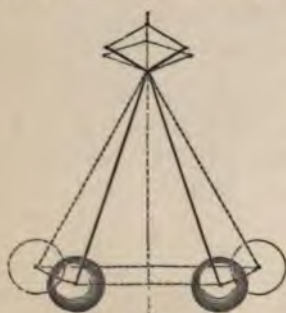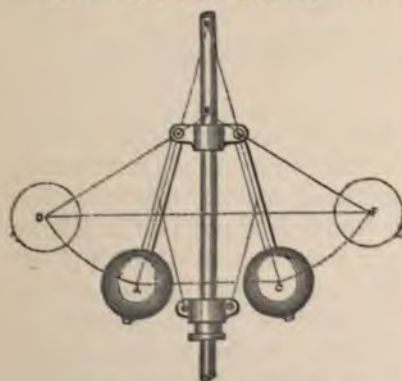
Fig. 431.—Ordinary Governor.

commonly employed. The arms are suspended from two separate pins, one on each side of the spindle. But, compared with the action of the Watt governor, the defect of variability in the height of the cone of revolution is increased; for whilst in the Watt governor the apex of the cone is stationary, it falls in this side-linked governor as the speed increases, whilst the balls at the same time rise, and the cone ABC, reduced above and below, may be compressed at last into the form DEF. As the height is shortened the speed is increased, and the governor by so much runs off with the engine, and misses its function. These remarks, of course, apply chiefly to extreme cases.

PARABOLIC GOVERNORS.

The opening or closing of the throttle-valve to any extent without demanding any alteration of the speed of the engine, is only to be effected when the balls in rising or falling describe a portion of a parabolic curve, for, in this case, the height of the cone is constant for all positions of the arms, and the balls are in equilibrium and will remain in any position, so long as the speed remains unchanged. But, on the contrary, they may fly from one end of their range to the other under the slightest alterations of speed. Mr. Head states that the earliest form of parabolic governor known in England, fig. 432, was introduced from Vienna in the Exhibition of 1851. The balls were suspended by links to rollers, which travelled upon arms branching from a vertical spindle, so formed that the centres of the rollers travelled in parabolic curves. A governor on this system was afterwards designed by Mr. Head, and applied to compound engines in a woollen mill. The governor was rendered useless by its excessive sensitiveness, continually disturbing the throttle-valve. The difficulty was then obviated by attaching an air-

Fig. 432.—Parabolic Governor.

cataract to the sliding-piece of the governor. In rising or falling the balls were caused to sink or to force air through a small adjustable aperture in the top of a cylinder; and in this way momentum acting vertically was prevented from accumulating. The parabolic governor, so modified, was quite successful.

HEAD'S PARABOLIC GOVERNOR.

A simpler form of governor, approximately parabolic, is obtained by the expedient of crossing the arms at the spindle, as in Farcot's governor, which was exhibited in 1862; and suspending them at points respectively on the sides of the spindle opposite to the sides on which the balls are situated. An efficient governor of this class is shown in fig. 433, designed and constructed by Mr. Jeremiah Head.[1] The method of setting out an approximate parabolic governor of this description is illustrated by fig. 434. The curve in strong lining is a true parabola; and a limited portion of it may be approximated to very closely by the circular arc shown in dot-lining, described from the centre L. First, the lowest position of the ball B is fixed according to convenience, and the height of the cone DF is determined according to the intended number of revolutions per minute. Draw BH at right angles to BF, and bisect DH for the point A, the vertex of the parabola. The total rise DE of the ball is then determined according to taste or opinion, the ordinate EC is drawn, and the length of it is calculated

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[1] See Mr. Head's paper on Steam Engine Governors, in the *Proceedings of the Institution of Mechanical Engineers*, 1871; page 213.

in proportion to the ordinate DB, as the square root of the abscissa DA is to that of the abscissa EA, by the properties of the parabola, thus:—

$$\sqrt{DA} : \sqrt{EA} :: DB : EC.$$

The point C is a second point in the curve, and intermediate points may be found in the same manner. Trace the parabolic curve through these points, and find by trial the centre L of a circular arc passing as nearly as possible through the points thus determined. The point L thus found is the centre of suspension for the ball on one side of the axis, and a centre
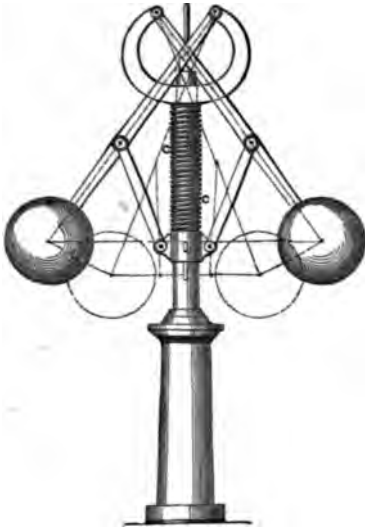
Fig. 433.—Head's Governor.
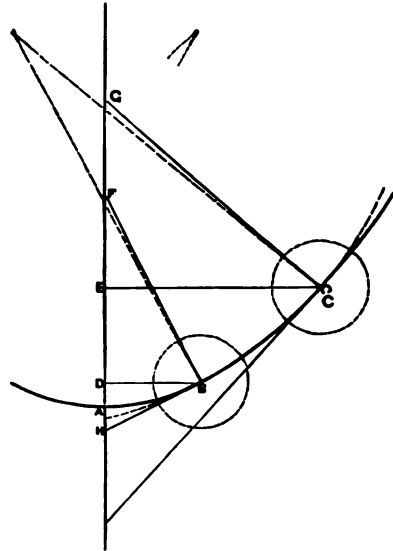
Fig. 434.—Setting out of Head's Governor.

similarly situated on the other side is the centre of suspension for the other ball.

As a check on the over-sensitiveness of the parabolic governor, fig. 433, a helical spring C is placed upon the spindle. It is not under compression, and is therefore inoperative when the balls are in their lowest position; but it opposes a slight and increasing obstruction to them by compression as they rise. In falling, on the contrary, the balls are urged to start slightly in anticipation of a decrease of speed, but the influence of the spring gradually disappears as they fall. The spring acts as a compensation for the slight inequality of the heights of the cones in the extreme positions. This inequality is due to the fact that the radial lines LC and LB do not coincide with the normal lines GC and FB; and that the height of the upper cone is a little greater than that of the lower cone, indicating that the balls are quiescent in their highest position at a somewhat lower speed than in their lowest position. This circumstance is neutralized by the spring, if suitably adjusted, as it acts to slightly depress the balls and so shorten the height of the cone.

Mr. Head states that several parabolic governors, as above described, are at work in the Newport Rolling Mills, where the proper speed is 40 revolutions per minute. In plate-rolling the speed is maintained uniform, whether the rolls be empty or occupied.

WEIGHTED GOVERNORS.

The resistance of a spring or of a heavy central weight, superadded to the ordinary Watt form of governor, materially augments its power, with its sensitiveness to changes of speed and its promptitude of action. The resistance of the mass of the balls may be distinguished from that of their gravitation. In some forms of governors—revolving on a horizontal axis—the gravitation of the balls does not play any part in this action, since the weights of the balls balance and neutralize each other. It is mass alone that operates; and, supposing that an ordinary two-ball governor be laid with its axis horizontal, and caused to revolve, the balls, if uncontrolled, would at once fly open and revolve, not in a conical figure, but in one plane with the arms, around the fulcrum. Suppose now a helical spring to be so placed in connection with the balls as to be gradually compressed in proportion as the balls extend from the axis: the resistance of the spring increasing uniformly with the extent of the compression, whilst the centrifugal force of the balls increases
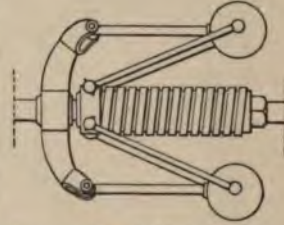
Fig. 435.—Porter's Marine Governor.

uniformly with the radius of revolution. If the resistance of the spring to compression balances the centrifugal force of the balls in any one position, they will balance in all positions, the angular speed of revolution being the same in all positions. Suppose, for example, a combination like that of Porter's marine governor, fig. 435, of a helical spring and a pair of governor-balls on a horizontal axis. Let the spring be compressed 1 inch in extent by a pressure of 500 lbs., then 500 lbs. more will compress it another inch, and 500 lbs. more—1500 lbs. together—another inch still. Let now the balls make 300 revolutions per minute in a circle 5 inches in diameter, and exert a centrifugal force of 200 lbs.; at the same speed, in a circle 10 inches in diameter, they will exert a centrifugal force of 400 lbs., and in a 15-inch circle, 600 lbs. Here it is seen that the ranges of action are inversely as the forces; that 3 inches of compression have been effected by a pressure of 1500 lbs., and that for $7\frac{1}{2}$ inches of radial action there is a centrifugal force of 600 lbs., and that $3 \times 1500 = 7\frac{1}{2} \times 600$. Thus, in all positions of the balls, they may remain in equilibrium with the spring, whilst the speed of revolution remains the same.

Suppose, now, that the governor is placed with its axis vertical. The gravitation of the balls comes into operation, and the conditions are altered. The balls are no longer in equilibrium in any position, unless the speed of revolution is increased as they extend outwards; and thus it

happens that spring governors and weighted governors are run at higher speeds than ordinary unloaded governors.

PORTER'S ALLEN GOVERNOR.

The weighted governor now in general use, in various forms, was introduced by Mr. C. T. Porter in 1862. It is in principle like the spring vertical governor. As applied to the 12-inch cylinder steam engine at the works of Messrs. Whitworth & Co., Manchester, it is shown in figs. 436.
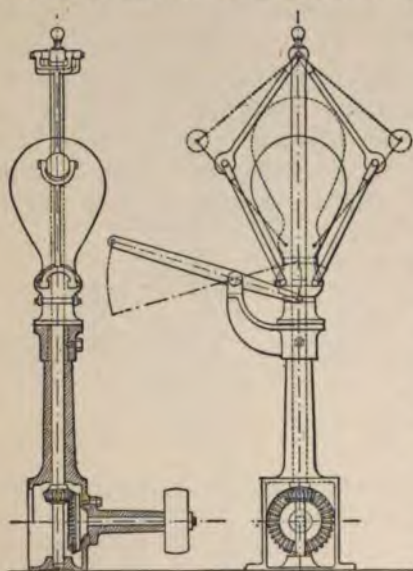
Figs. 436.—Porter's Allen Governor. Scale 1/16th.

It consists of two very small revolving balls, weighing from 2 to 3 pounds, according to the size, moving at a high speed, of from 320 to 400 revolutions per minute, with sufficient centrifugal force to sustain a counterpoise or heavy central weight sliding on the spindle, from 50 pounds to 300 pounds. The central weight forms part of the slide or sleeve, and is linked to the balls with rods of the same length as the arms of the governor, forming with the arms a parallelogram. Thus, the vertical range of the counterpoise is twice that of the balls; and as the obliquity of the arms increases as the balls rise with increase of speed, the resistance of the counterpoise to vertical elevation is also increased with the speed—in so far coping with the greater centrifugal force of the balls, in the manner of the spring with its increasing resistance to compression. The radius rods are centred in the axis of the spindle, to which they are connected with widely-forked ends, as shown, fitted on a transverse pin. The lateral resistance by friction due to the turning of the arms on the central pins is thus much reduced when compared with the pressure and friction on the joints of arms as ordinarily hung.

According to the afore-stated analysis, the centrifugal force of the revolving balls in a spring-loaded or weighted governor, is divisible into two parts—of which one, reckoned for a constant speed, is neutralized by the spring or the weight; and the other, reckoned for a variable speed, is absorbed in counteracting the gravitation of the balls. Taking the second of these as cumulative upon the first, the augmentation of velocity is less than the velocity, reckoned from a state of rest, that would be required to generate an equal centrifugal force if the governor were divested of spring and counterweight. Suppose, for instance, that in the spring governor a speed of 200 revolutions per minute suffices to balance the resistance of the spring, and that the governor is run at a speed of 300 revolutions per minute to provide centrifugal force in addition to balance the gravitation of

the balls in their normal position. The centrifugal forces at the two speeds are in the ratio of the squares of the speeds, or as 200^2 to 300^2, or as 1 to 2.25; showing an augmentation of the ratio of 1.25, equal to $1\frac{1}{4}$ times the centrifugal force neutralized by the spring. Now, to generate the centrifugal force required for the plain governor, to counteract gravitation, expressed by the proportional value 1.25, the speed required is $(200 \times \sqrt{1.25} \div \sqrt{1} =)$ 224 revolutions per minute, or $2\frac{1}{4}$ times as much speed as sufficed to generate the required force in the spring governor above that which was neutralized by the spring. Bearing in mind that the speed required for balancing the spring is constant, the variation of speed in the spring governor applies only to the augmentation-speed, or that generated for balancing the gravitation of the balls. This augmentation, or margin of variable speed, it has been shown, in the above example, is only two-fifths of the speed required in the plain governor; and the variation of speed must be approximately in the same proportion.

It may be concluded generally that the spring governor or the weighted governor is subject to much less variation of speed than the plain governor, for different extensions of the balls. Conversely, the play of the balls is much greater for given variations of speed, and the governor is more sensitive and more prompt in action.

The combination of the spring with the cross-arm governor, by Mr. Head, already noticed, page 68, comprising elements of sensitiveness and promptitude of action, provides for the running of the governor at a higher speed than if the spring were omitted.

GALLOWAYS' PARABOLIC GOVERNOR.

The weighted cross-arm governor of Messrs. Galloways, fig. 421, page 55, also combines elements of sensitiveness and promptitude of action,—an approximately parabolic path of the balls, with dead weight.

In their recent design of counterweighted governor, figs. 437, Messrs. Galloways provide an inverted parabolic action. The balls, so called,— literally, in this case cylinders,—are suspended from the two ends of a crosshead keyed on the

Figs. 437.—Galloways' Parabolic Governor. Scale 1/12th.

top of the spindle. They have each an axle, the ends of which are supported by and turn in the links; and they roll on the outer surfaces of two inclined slots in the counterweight, which are so formed that the centre of each roller travels in a parabolic path relatively to the weight. They, in fact, travel upwards or downwards in the parabolic slots, or they with the counterweight rise or fall; but the relative travel is effected for the most part by the rising or falling of the weight. The parabolic path is

inverted, as compared with that of the ordinary parabolic governor, fig. 433.

The governor illustrated by figs. 437, is No. 5 parabolic governor, making 297 revolutions per minute. The spindle is 1¼ inches in diameter. The crosshead at the top is keyed to it; and the rollers are suspended from it, at centres 5 inches apart. The rollers are each 2½ inches in diameter and 5⅛ inches in length; and they each weigh 7 pounds. The counterweight is formed out of a block 14⅜ inches by 5 inches wide, and 6¼ inches deep. It is bolted to the sleeve on the spindle, and the two together weigh 87½ pounds. It slides on the spindle and revolves with it, being carried round by a feather let into the spindle.

HARTNELL'S GOVERNORS.

Mr. Wilson Hartnell introduced, at the Cardiff show, in 1872, a form of governor applied to ordinary slide-valves, designed specially for portable engines.[1]   The design was based on the consideration that great governing power could be obtained by placing the governor in the fly-wheel; and that,

Fig. 438.   Fig. 439.   Fig. 440.
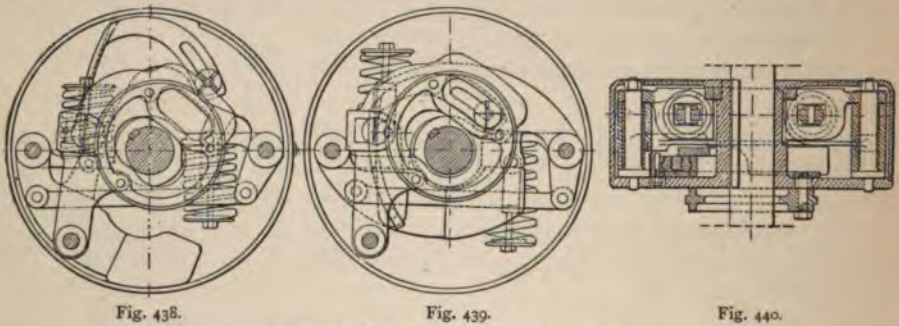
Hartnell's Automatic Governor.   Scale 1/12th.

with so much power, it would be easy to move the eccentric and by some form of wedge-gear to hold it when moved. But it was found that sufficient power could be obtained within a much less diameter than that of the fly-wheel, and separate governor-drums were adopted.

Governor applied to Ordinary Slide-valves.—The governor used for a portable engine of 8 or 10 horse-power is shown in figs. 438, 439, and 440. The mechanism is inclosed in a case 18 inches in diameter. Two weights are pivoted to two pins near the circumference; they are opposed to each other and are connected by a link, so as to maintain a balance. They are shown fully open in fig. 438, and closed in fig. 439. The degree of openness of the weights is dependent on the speed, the centrifugal force being counteracted by two helical springs. The eccentric for driving the valve is outside the case, and is fastened to a carrier inside by means of three stud-bolts which pass through slots in the disc-plate of the drum. The carrier swings on a pin fixed near the circumference of the drum, and so

[1] See a paper by Mr. Wilson Hartnell, "On Governing Engines by Regulating the Expansion," in the *Proceedings of the Institution of Mechanical Engineers*, August, 1882, page 408.

shifts the eccentric transversely across the shaft, varying its eccentricity and its effective throw, whilst the lead is constant. The eccentric is shown in mid-gear with the weights open in fig. 438, and in full-gear with the weights closed in fig. 439. The eccentric is shifted according to the open-ness of the weights by means of a quadrant, so called, or cur-vilineal bar, one end of which is fixed to one of the weights, and the other end plays through a slotted pin fixed on the eccen-tric-carrier. The quadrant is struck with a radius equal to its distance from the pivot of the weight, but it is not concentric with the pivot. It is fixed ec-centrically so that, as it plays to and fro through the slotted pin,

Fig. 441.—Hartnell's Automatic Governor: Indicator Diagrams.

it gradually shifts the carrier laterally, towards or from the shaft, and so also the eccentric; thereby varying the throw of the eccentric, the travel of the valve, and the period of admission.

The indicator diagrams, fig. 441, taken for the automatic governor, with the single slide-valve, resemble those pro-duced by link-motions.

Another form of governor, which Mr. Hartnell designates an Automatic Expansion Regulator, is shown in figs. 442. It is par-ticularly suitable for separate expansion-valves. The balls are on inverted arms, forming parts of bell-cranks, the horizontal arms of which bear, by means of rollers, on the sleeve or slide through which the mo-tion is given off. A helical spring, inclosed

Figs. 442.—Hartnell's Automatic Expansion Regulator. Scale 1/10th.

in the upper part of the governor, surrounding the spindle, is acted on by the sleeve as it rises and falls, and is compressed or relaxed accordingly. There is a correspondence between the increasing effect of the gravity of the balls as they are extended and inclined outwards, and the increasing

resistance of the spring.   The cut-off is varied by means of link-gear, in which the link, moved by the eccentric, vibrates on a pin through its
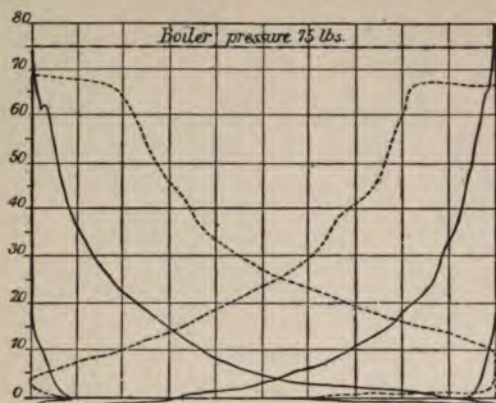
Fig. 443.—Hartnell's Automatic Expansion Regulator: Indicator Diagrams.

upper end, and the sliding-block is raised or lowered by the action of the governor on the radius-rod connected to the valve-spindle: so varying the travel of the valve and the cut-off.   The gear is so arranged that, with a mean load, the eccentric-rod and radius-rod are in line, and there is little or no slip of the block in the link.   The indicator diagrams, fig. 443, were taken from a cylinder fitted with this expansion gear.

PROELL'S GOVERNOR AND EXPANSION GEAR, WITH TRIP-MOTION.

Proell's governor, figs. 444, resembles an ordinary governor inverted. It is weighted round the spindle, and the fulcra of the arms are attached to the weight.   The movements of the balls are therefore upwards as well as outwards.   The arms are pinned to bell-crank levers, having their fulcra at the top of the spindle.   From the upper and shorter arms of these levers, vertical movement is communicated through a transverse bar to a central rod which passes down through the spindle, by means of which the cut-off can be varied by the action of the governor.   The distribution of the steam in the cylinder is effected by means of the ordinary slide-valve; and the variable cut-off is effected by means of a double-beat valve, the spindle of which is looped at the upper end to receive the extremities of the lifting levers.   The outer arms of these levers are fitted with steel bearing plates, which are acted on by the vertical arms of two bell-crank levers hung on the ends of a transverse rocking lever which receives its motion from an eccentric on the main shaft.   The vertical vibration of the rocking lever is communicated to the fulcra of the bell-crank levers; and as the horizontal arms of these alternately are stopped by projections on a forked piece which is fastened to the lower end of the central rod of the governor, the outer arms are turned inwards as the ends of the rocking lever and the fulcra descend.   The forked piece is so formed simply to clear the transverse shaft on which the rocking lever is fixed.   The outer arms of the bell-crank levers are formed with steel bearing pieces, which act on the outer ends of the lifting levers; and in turning inwards they slide out of contact with the lifting levers.   These are thus alternately set free, when they fall and close the double-beat valve.   The fall is accelerated by a helical spring on the axis of each lifting lever, in a state of compression; and it is softened by the medium of a shallow dashbox under the

levers, in which the air-cushion may be so adjusted that the valve may fall to its seat without shock. To prevent the governor from hunting, a suitable moderator of a very simple kind is employed. That part of the spindle on which the counterweight slides is made to two different diameters, to which the counterweight is exactly fitted. To ensure air-tightness
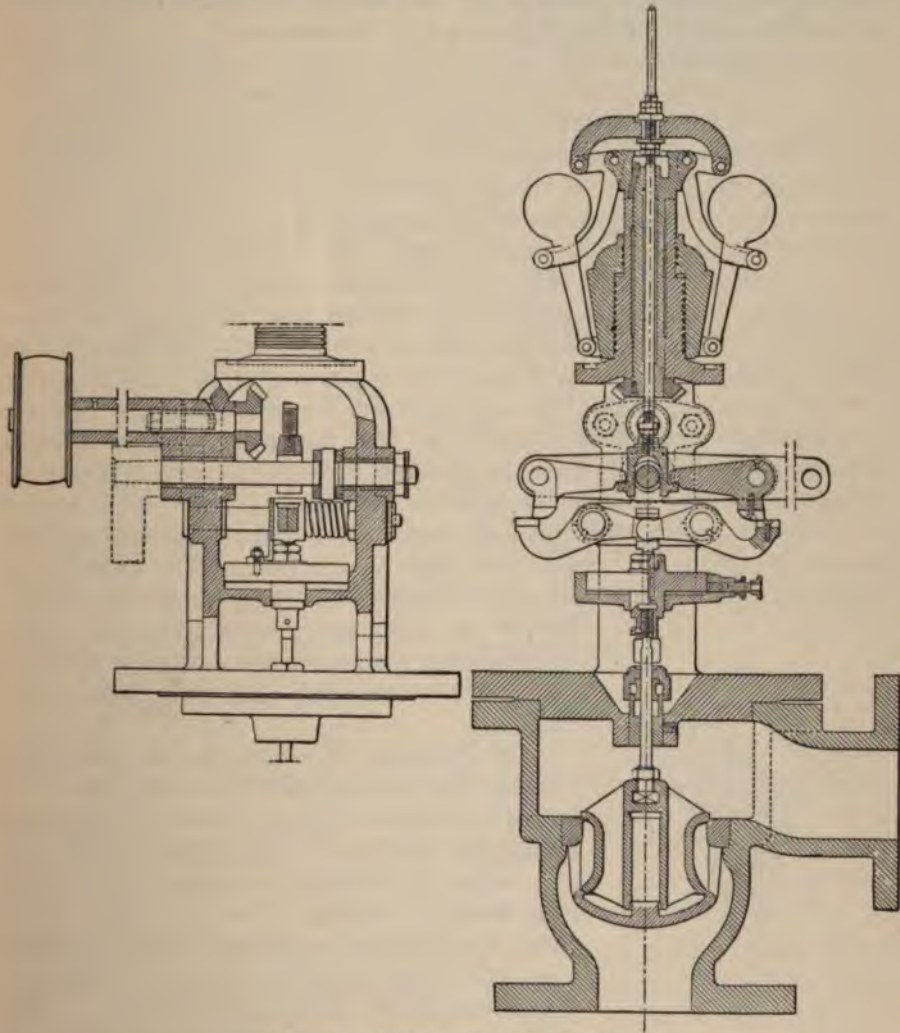
Figs. 444.—Pröell's Governor. Scale 1/6th.

a number of grooves are turned in the interior of the counterweight. When the counterweight rises it forms an annular air-space with the spindle, which increases as the weight rises. By means of a suitable set-screw the inflow and outflow of the air may be adjusted at will, and hunting is obviated. The governor is driven by a band over a pulley, through mitre-wheels.

The variation of the cut-off depends on the extent of the overlap or contact of the steel faces of the bell-cranks and the lifting levers, allowed by the governor. The overlap, and consequently the period of admission, are greatest, when the governor is down. The maximum width of overlap varies from $3/16$ inch for a 2-inch valve, to ½ inch for a 9-inch valve. Within these ranges of overlap, the automatic determination of the cut-off varies from 0 per cent to 75 per cent of the stroke. As the arms of the bell-crank levers are in the ratio of about 1.75 to 1, the total lift of the governor-rod is proportionally less than the overlap, and ranges from ⅜ inch to ⅞ inch for valves of from 2 inches to 9 inches in diameter. The shortness of the movement required of the governor-rod is taken advantage of by limiting the opening of the governor-balls, or the resulting lift of the counterweight relatively to the lift of the governor-rod in the ratio of about 4 to 1, by means of the bell-crank levers and cross-bar at the top of the governor already noticed. By such reduction of movement, the power of the governor, inversely, is increased, for the purpose of altering the rate of expansion. The power, for a variation of one per cent of the speed of the counterweight, ranges from 1 pound to 2 pounds, exerted by the several sizes of governor; and in the governor-rod, correspondingly, a power of from 4 pounds to 8 pounds is available. But the power required to lift the valve is supplied entirely from the eccentric, through the rocking lever; and the sole duty of the governor is to set the bell-cranks centred on the rocking lever for the proper overlap of the steel faces, and to maintain them in position for gliding the upper steel faces off the lower. The power of the governor is thus amply sufficient. The speed of the governor ranges from 180 to 120 turns per minute, according to size. By weighting the governor-rod, the speed may be increased fifty per cent, while the engine is running.

The governor is constructed of four sizes, suitable for steam-pipes of from 2 inches to 9 inches in diameter. In the governor represented by fig. 444, which is of No. 1 size, the balls are 2⅛-inches in diameter, on arms $47/16$ inches long between centres. The bell-crank levers above by which the movement is taken off have arms 3⅞ inches and $1 1/16$ inches long, reducing the movement in the ratio of 3.65 to 1. The rocking lever is 7 inches long between the fulcra of the bell-crank levers; and these have arms 2⅝ inches and $1 5/16$ inches long, making a leverage in the ratio of 2 to 1. The lifting levers have arms of equal lengths, 1¾ inches. The dashpot is 3⅞ inches in diameter, the double-beat valve is 3⅞ inches in diameter at the upper seat, and 3¾ inches at the lower seat. The width of bearing on each seat is ⅛ inch. The valve is guided on a central pin or stud, and its maximum lift is ½ inch.

Fig. 445.—Proell Governor, earliest form. Scale 1/10th.

The Proell governor, in its earliest form, as adapted for giving off movement in the ordinary manner, by a sleeve, is illustrated by fig. 445, showing size No. 1. The balls are 3½ inches in diameter, on arms 7 inches long between centres. The hanging links are 6 inches long; and the maximum lift is 1½ inches. A heavy counterweight is placed on the spindle; it is one piece with the sleeve; and the arms of the balls are pinned to it at the lower part. The normal speed of the governor is 120 turns per minute.

THE "ACME" GOVERNOR.

The Acme governor, figs. 446, consists of two "balls" or hemispherical flyers, formed like the halves of one large ball, connected transversely and
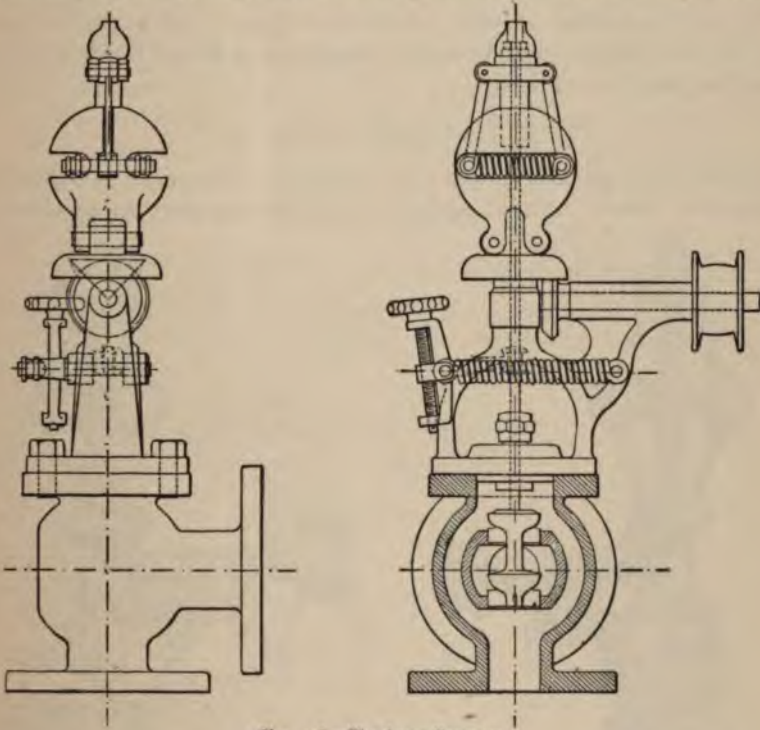
Figs. 446.—The Acme Governor.

controlled by a pair of helical springs; and an adjustable apparatus for partially raising or lowering the central spindle, whereby the normal speed of the governor, and, of course, that of the engine, may be varied.

The two half-balls are hinged at their lower ends to a lower crosshead and are connected by links to an upper crosshead. The transverse springs by which they are tied are attached to the centres which take the suspending links. When the speed is sufficient to cause the balls to open, against the resistance of the springs, the upper crosshead is pulled down by the connecting links, and so depresses the central spindle, which is connected at the lower end to an equilibrium-valve in the steam-pipe. The supply of steam is thus regulated.

In order to vary the speed at which the balls begin to move outwards, and thus also the speed of the engine, the horizontal arm of a double bell-crank lever pivoted to the frame, engages in a sleeve fastened on the central spindle. The two other arms of the lever give bearings to a screw, having a milled head, by which it may be turned, and so the position of a nut on the screw may be adjusted. The nut is connected by a helical spring to any convenient part of the frame, and is under pressure from the spring which is in a state of tension. When the nut is screwed towards the upper end of the lever, the spring, connected to it, puts a stress on the lever and causes a downward pressure on the central spindle. When, on the contrary, the nut is screwed downwards, the stress of the spring results in an upward pressure on the central spindle. Correspondingly, the stress of the tie-springs on the balls is counteracted or supplemented, and the normal speed is altered as may be required.

THE PICKERING GOVERNOR.

The Pickering governor, figs. 447, consists of two or more balls carried on upright or nearly upright springs, fixed by the ends to two discs, an
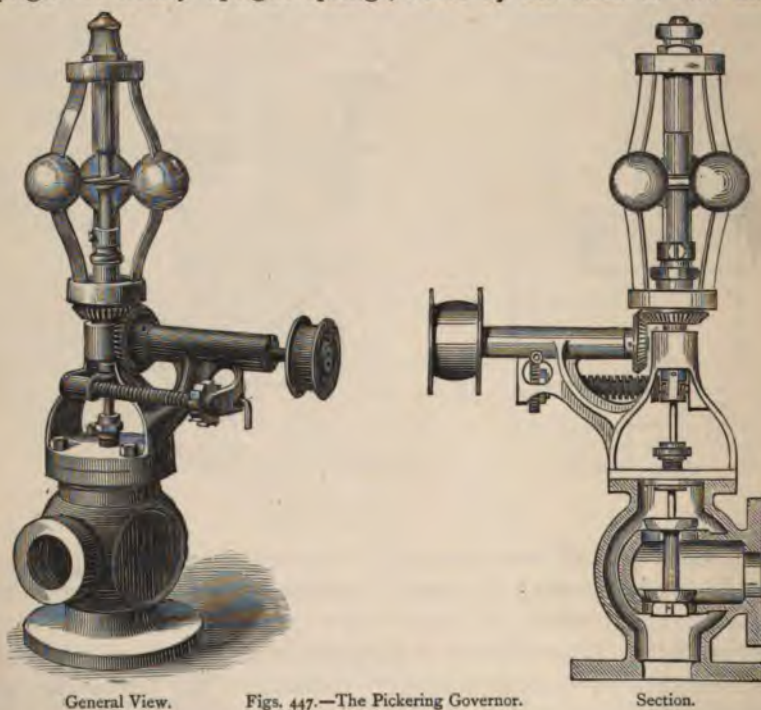
General View.   Figs. 447.—The Pickering Governor.   Section.

upper and a lower, which are placed on a tube. The lower disc is free to rotate, but it is prevented by a collar from rising. The upper disc, besides rotating, is free to rise and fall. The system of balls, springs, and discs, is put together without movable joints of any kind, and the centrifugal movement of the balls is permitted by the simple flexure of the springs. The

springs are strips of thin steel, of ogee or cyma form, above and below the balls, to ensure the needful degree of flexibility and range. Rotary motion of the balls, as well as of the upper disc, is communicated through the springs. These are driven by the lower disc, which is fastened to and is driven by the mitre-wheel through which the driving power is transmitted.

By the rotative expansion of the system of springs, the upper disc is drawn downwards on the tubular spindle, and with it the central rod, the lower end of which is connected to an equilibrium steam-valve in the steam-pipe, for the regulation of the supply of steam.

The normal speed of the governor may be altered by means of an adjustable arm fixed on one end of a horizontal shaft, forked to take into a grooved collar on the central rod. The shaft is turned by means of a worm-wheel and thumb-screw worm motion at the other end of the shaft, through the medium of a helical spring connecting the worm-wheel with the lever. In proportion as the spring is tightened by the turning of the worm-wheel, it causes an upward pressure of the forked lever on the central rod, counteracting to that extent the weight of the balls, and so varying the speed of the governor as required.

KNOWLES' AUTOMATIC SUPPLEMENTARY GOVERNOR.

Knowles' supplementary governor, constructed by Messrs. Hick, Hargreaves, & Co., is designed to correct the changes of speed which, to a
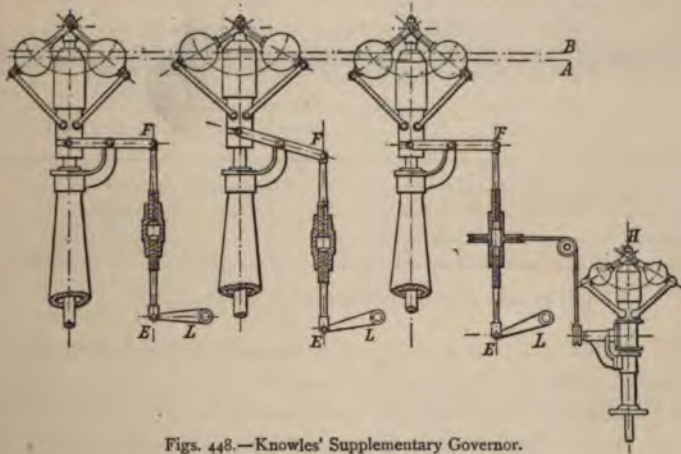
Figs. 448.—Knowles' Supplementary Governor.

greater or less extent, take place with every variation of load or of steam pressure. For an engine working at 500 indicator horse-power, for example, making 50 turns per minute, with a pressure of 50 lbs. per square inch in the boiler, let the position of an ordinary governor be represented by figs. 448, the balls revolving in their normal plane, A. The connecting link, EF, is 2 feet 5 inches long between centres, and the screwed ends of the link within the nut are 3 inches apart. When 100 horse-power of work is thrown off, the boiler pressure continuing the same, the speed is

increased, and the governor-balls rise and revolve in a higher plane, B.
Until the proper load is reinstated, the engine continues to run at the
over-speed corresponding to the higher plane of revolution; and if the
engine is to resume the proper speed,—50 turns per minute,—when work-
ing only 400 horse-power, the governor-balls must drop from the plane B to
the plane A, and the inclination of the cut-off lever L must be still greater
than is shown in the figures, so that just the quantity of steam required to
drive the engine at 50 turns per minute is admitted. For this object, the
length of the rod EF must be increased to, say 2 feet 8 inches, its screwed
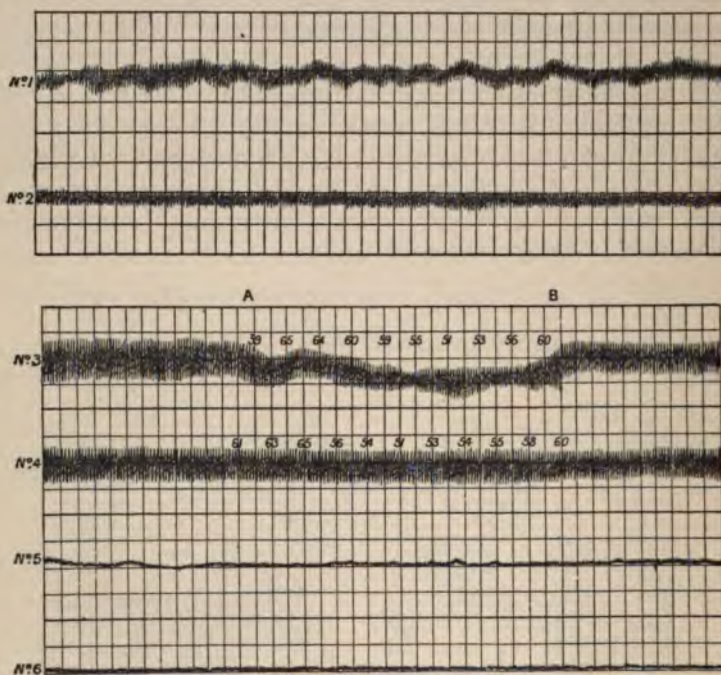
Figs. 449.—Diagrams by Moscrop's Recorder. Scale ¼.

ends being 6 inches apart, as shown. The adjustment of length is performed
by the engineer, who turns the nut by hand.

Such adjustment is performed automatically by the supplementary
governor H. A friction-pulley is hung between the flanges of the sleeve on
the spindle, with the smallest practicable clearance, in order that, by the
slightest variation of speed, the upper or the lower flange presses on the
wheel and rotates it one way or the other. The rotatory motion is conveyed
by a cord over a grooved pulley fixed on the shaft of the friction-pulley to a
pulley fixed on the adjusting nut of the main governor, by which the nut is
operated automatically and continuously, and the speed of the engine
maintained sensibly constant.

To illustrate the action of the supplementary governor, copies of
diagrams taken from several steam engines by Moscrop's recorder are given,

to a scale of half full size, in figs. 449 and 450. The recorder is afterwards described, page 83.

No. 1 diagram was taken from a beam engine, fitted with an automatic cut-off, controlled by a high-speed governor. The variations from a straight course indicate variations of speed. The intervals between the horizontal lines correspond with an increase or a decrease of 4½ per cent of the speed, and the vertical lines mark intervals of five minutes. Two kinds of irregularity of speed are recorded: one is the general variation arising from imperfection of governing; the other is the variation that takes place during each stroke, indicated by the breadth of the diagram or mark, which is a measure of the oscillation of the recorder in the course of each stroke. These oscillatory movements are evidence of the insufficiency of weight of the fly-wheel. No. 2 diagram was taken from the same engine, after the supplementary governor was applied to the engine: proving that the general speed was practically uniform, although the variation of speed in the course of each stroke remained unaltered.

Nos. 3 and 4 diagrams were taken from a horizontal tandem compound engine, fitted with the supplementary governor, which was thrown out of gear at the point A, when the No. 3 was taken, and again connected at the point B. The want of uniformity of speed is evident, the variation amounting to 4½ per cent. The steam-pressures were noted, as

Figs. 450.—Diagrams by Moscrop's Recorder. Scale ½.

marked, during the interval A B; and again along the corresponding part of the diagram No. 4, when the governor was connected. A uniform speed was maintained for No. 4, although the pressure in the boiler varied, during the intervals A B, between 65 lbs. and 51 lbs. per square inch. The particular variation in the course of each stroke appears to have been about 5 per cent.

Nos. 5 and 6 were taken from a horizontal Corliss engine, indicating 1000 horse-power, before and after connecting the supplementary governor. The variation of speed originally did not exceed about 1 per cent; but this was obviated, and the speed was rendered practically uniform by the supplementary governor. The special variation of speed in the course of each stroke was about two-thirds of 1 per cent.

Mr. Michael Longridge[1] gives several suggestive examples of the action of steam engines as recorded. No. 7 was taken from a pair of M'Naughted beam-engines, coupled at right angles, fitted with an ordinary low-speed Watt governor, and an equilibrium throttle-valve; indicating 1550 horse-power. No. 8 is the record with a supplementary governor. The cylinders are 43 inches and 63 inches in diameter, with strokes of 4 feet and 8 feet. The fly-wheel is 24 feet in diameter, and weighs 70 tons. The variation of the general speed was originally upwards of 10 per cent, and was entirely removed when the additional governor was applied. The variation in the course of each stroke is $4\frac{1}{2}$ per cent.

A M'Naughted beam-engine in a cotton-mill, had 36-inch and 42-inch cylinders, having $3\frac{1}{2}$ and 7 feet strokes; with a $22\frac{1}{4}$-feet fly-wheel, weighing 22 tons, making $28\frac{1}{2}$ turns per minute. The engine indicated about 410 horse-power. The diagram No. 9 shows that the speed varied 23 per cent in the course of each stroke; and that the fault was due to insufficient power of fly-wheel. Ten tons was added to the weight, and the speed was increased to 33 turns per minute, when a marked improvement was effected, as shown by No. 10 diagram, indicating a variation of 13 per cent in the course of the stroke. It is remarkable that the general speed of the engine, both before and after the alteration, was nearly uniform.

A supplementary governor was added to the engine, and it produced the diagram No. 11, showing that the variation of speed in the course of the stroke was reduced to about 11 or 12 per cent. The pressure in the boiler was gradually reduced from 59 lbs. at 3 o'clock, to 45 lbs. at 3 h. 45 m., making a fall of 25 per cent. At 4 P.M. the pressure was got up to 60 lbs., after which about 30 per cent of the load was suddenly thrown off. Yet the axis of the diagram was practically a straight line.

Admitting the efficiency of the Knowles governor, with its means of instant action, it seems feasible to apply the same expedient to the main governor, and so render unnecessary the application of a second or auxiliary governor.

POLLITT AND WIGZELL'S COLLAMORE GOVERNOR ATTACHMENT.

The object of the Collamore attachment is to meet the objection to ordinary governors already stated in noticing Knowles' governor. The principle of the attachment is, that whilst the planes of revolution of the governor-balls, and with them the cut-off or the position of the

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[1] See Mr. Michael Longridge's paper, "On the Moscrop Engine Recorder, and the Knowles Supplementary Governor," in the *Proceedings of the Institution of Mechanical Engineers*, May, 1884.

equilibrium-valve, are altered automatically, the speed of the governor and of the engine remains the same, and the cut-off is varied according to the requirement for steam. This action is effected by pivoting a tumbling weight on the base of the governor, which may fall to the right or to the left, and by its gravitation correspondingly lower or raise the central weight and the balls, by the medium of a toothed sector and a rack. The sector is fixed on the pivot of the tumbling weight, and the rack is fixed to the sleeve at the base of the central weight. When the engine works with its regular load and at its proper speed, the attachment weight is vertically over its pivot, and is therefore neutral; but if there be any alteration of speed, the weight is turned on its pivot by the action of the vertical rack, and falls to one side or the other as required, and assists in increasing or diminishing the supply of steam without an alteration of speed.

THE MOSCROP ENGINE RECORDER.

The engine recorder is an apparatus for continuously measuring and recording the speed of a steam engine. It consists of a clock to note the time, and to give uniform motion to a paper tape; a centrifugal governor, driven by a band from the engine, and a marker connected with the governor in such a manner that its position on the tape depends on and changes with the speed of the governor. The action of the recorder in marking the tape has already been explained and illustrated, pages 80 to 82.

CHAPTER VI.—EQUILIBRATION OF THE STEAM ENGINE.

The earliest published recognition of the influence of the inertia of the reciprocating parts on the working of a steam engine appears to have been made by Mr. John Watt, in 1839. "It is observed," he says, "that engines working expansively pass the centre more easily than when working full pressure throughout the stroke."[1]

Mr. Wm. M'Naught, of Rochdale, in 1845, fairly appreciated the reality and importance of the reciprocating function.[2] He maintained that "the system of cutting off steam is beautifully adapted to high velocities, inasmuch as the $\pm$ pressures may be made to nearly compensate for the variation in the pressure of the steam."

Mr. G. H. Strype, in 1863, investigated the influence of the inertia of the reciprocating members in connection with the expansive action of steam.[3] He clearly showed that by suitable combinations of speed and

[1] See Mr. Watt's communication "On the Economy of Working Expansively in Crank Engines," in the *Minutes of Proceedings of the Institution of Civil Engineers*, 1839; page 44.

[2] See Mr. M'Naught's letter "On the Velocity of Pistons in Steam Engines," in *The Practical Mechanic and Engineer's Magazine*, 1845, page 248; in which he submits the question to analysis.

[3] See Mr. Strype's paper "On the Influence of the Inertia of the Reciprocating Parts of Steam Engines, and its Effects in connection with the Expansive Action of Steam," in the *Transactions of the Institution of Civil Engineers in Ireland*, 1861–63, vol. vii.; page 144.

expansive working in relation to the reciprocating mass, the effect is beneficial in equalizing the motive power on the crank-pin during the stroke. Mr. Strype demonstrated that the accelerating force in the first half of the stroke varied as the cosine of the angle formed by the crank with the centre-line, and consequently that it was a maximum at the dead-point, and diminished uniformly in the course of the motion of the piston, till the crank arrived at its half-stroke, where it vanished; and that, correspondingly, the retarding force, which was nothing at half-stroke of the crank, was uniformly increased in the ratio of the cosine of the angle of the crank, and became a maximum at the end of the stroke. Mr. William Anderson, in the course of discussion on the paper,[1] showed that the accelerating and retarding forces at the beginning and the end of the stroke were, in fact, the centrifugal force of the reciprocating parts—taken as revolving masses—calculable by the usual formula.

Mr. Charles T. Porter exhibited, at the International Exhibition of 1862, the Porter-Allen engine, specially designed for working at high speeds of from 600 to 750 feet of piston per minute, in such a manner that the pressure on the crank-pin should be practically equalized during the stroke, with a considerable degree of expansive working. In 1868, Mr. Porter published a demonstration of the resistance of the reciprocating parts with the aid of a table of versed sines.[2]

Now, let ABCD, fig. 451, be the path of the crank-pin, and let A*a* represent the magnitude of the centrifugal force of the reciprocating parts connected to
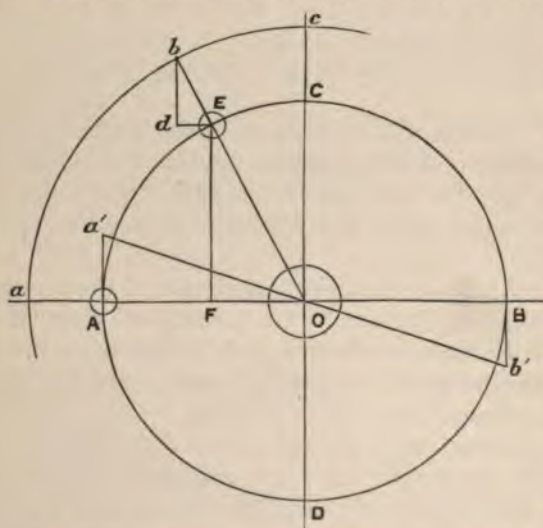
Fig. 451.—Equilibration of Steam Engines: Centrifugal Force.

the crank-pin A at the dead-point, and draw the circular arc *abc* to represent the limit of what the centrifugal force would be all round the half-stroke AEC of the crank, if the reciprocating parts were collected at the crank-pin, and revolved with it. In any position, OE, of the crank, the extension E*b*, equal to A*a*, would, on this supposition, represent the centrifugal force. Draw the perpendicular EF, and the parallels *bd* and E*d*. Inasmuch as the reciprocating parts resist in the longitudinal line E*d* parallel to the centre-line, and not radially in the line E*b*, the suppositious force E*b* is to be decomposed into the suppositious force *bd*, and the force E*d*

[1] See the paper, page 167.
[2] See *Description of Richards' Improved Steam-engine Indicator*, 1868; page 105.

which is the measure of the actual resistance of the reciprocating parts to acceleration of longitudinal velocity. Now the triangle Ebd is similar to the triangle OEF; and if the radius AO or EO of the crank be taken as the measure of the centrifugal force at the dead-point A, then, similarly, the segment OF is the measure of the resistance of the reciprocating parts to acceleration, at the intermediate point E. When the crank is in the position OC, the resistance to acceleration, by construction, vanishes; and, for all other positions of the crank in the quadrant AEC, the resistance to acceleration longitudinally is measured by the segment, say OF, of the radius, cut off by the perpendicular EF, from the end of the radius, say OE. It follows that the resistance of the reciprocating parts is a maximum at the dead-point A, and diminishes uniformly through the half-stroke AO, from the beginning of the stroke A to the position of half-stroke O. This diminishing force is represented by the triangle Aa'O, in which Aa', equal to Aa, is drawn perpendicular to the centre-line, and the line a'O is drawn to the centre. Ordinates to the base-line AO measure the force at the points from which they are drawn. Producing the line a'O below the centre-line to b', where it meets the perpendicular Bb', the triangular space OBb', similarly, represents the graduated retarding force in the second half of the stroke OB.

The centrifugal force of a revolving body varies as the square of the linear or circumferential velocity; inversely as the radius of the circle of revolution or of gyration, when the linear velocity is the same; and directly as the weight of the revolving mass. The work in the revolving mass due to the linear velocity is $\dfrac{wv^2}{g}$, and the centrifugal force is,—

Centrifugal Force—General Formula.

(When the radius is expressed in feet)......$c = \dfrac{wv^2}{gr} = \dfrac{wv^2}{32.2\,r}$ .... (1)

(When the radius is expressed in inches)...$c = \dfrac{12\,wv^2}{gr} = \dfrac{wv^2}{2.683\,r}$ .... (2)

c = centrifugal force, in pounds.
w = weight of the revolving body, in pounds.
r = radius of gyration or of revolution, in feet or in inches, which may be measured as to the centre of the revolving body—in the present case the crank-pin.
v = linear velocity of the revolving body, in feet per second.
g = 32.2, the expression of gravity.
N = revolutions per second.
n = revolutions per minute: (coefficient .00034 = 1.225 ÷ 60²).

In terms of angular velocity, or the number of revolutions per unit of time, the centrifugal force varies as the square of the angular velocity, as the radius of the circle of revolution or of gyration, and as the weight of the revolving mass. The linear velocity is equal to the product of the angular velocity by the circumference of the circle of revolution, which is 3.1416 times twice the radius, or 6.283 rN, in which N is the number of

revolutions per second.   By substitution in formula (1) and reduction,

$.8165\, c = w\, r\, N^2$, and $c = \dfrac{w\, r\, N^2}{.8165}$, or—

Centrifugal Force, in Terms of Angular Velocity.

(Radius in feet)............$\begin{cases} \quad c = 1.225\ w\,r\,N^2 \dotfill (3) \\ \text{also } c = .00034\ w\,r\,n^2 \dotfill (4) \end{cases}$

(Radius in inches)...............$\begin{cases} c = .102\ w\,r\,N^2 \dotfill (5) \\ c = .0000283\ w\,r\,n^2 \dotfill (6) \end{cases}$

Dividing the coefficients in formulas (3) and (4) by 12, the formulas (5) and (6), thus modified, express the centrifugal force when the radius is given in inches.

With the aid of these formulas the problems of centrifugal action in the working of steam engines—in the reciprocating mechanism, the fly-wheel, and the governor—may be solved.

The initial resistance of the reciprocating parts of the steam engine, thus calculated, may be divided by the area of the piston in square inches, to give the equivalent resistance per square inch, which may be set off as an ordinate on the indicator diagram, positive at the beginning of the stroke and negative at the end of the stroke. A straight diagonal line drawn to join the ends of the ordinates, as shown in page 87, defines the alternate decrease of accelerating force and increase of retarding force. For instance, to adopt one of Mr. Porter's illustrations, fig. 452, in which the indicator diagram has been taken from a non-condensing cylinder, cutting off at one-fifth of the stroke; the point *b* is measured off at the required height by scale above the base-line *a*, at the beginning of the stroke.   From the point *b* a diagonal is drawn, crossing the line of counter-pressure at the middle of the diagram, and continued to the end. Two triangles are inclosed, the first, at the right hand, shown blank, representing at every point of the half-stroke the force exerted to impress the accelerating velocity of the re-ciprocating parts; and the second, at the left hand, shown tinted, representing the pre-cisely opposite force exerted to stop them during the second half-stroke. The curved end of the lower triangle shows the extent to which the motion of the parts is arrested by the compression at the other face of the piston, and not by the crank.
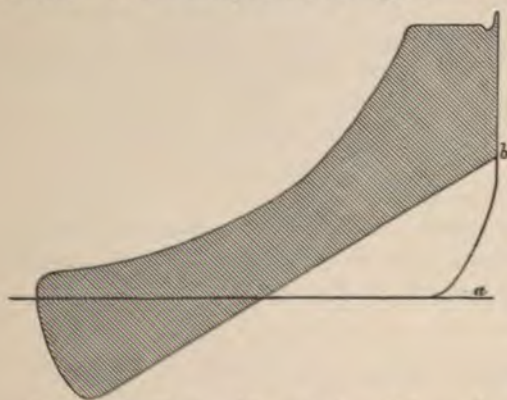
Fig. 452.—Equilibration of Steam Engines:—Influence of Accelerating and Retarding Force on Indicator-power.

Here, the weight and the speed of the reciprocating parts are such that their initial acceleration requires about one-half of the initial effective

pressure of the steam in the cylinder. The crank is relieved of one-half of the pressure at the commencement of the stroke, whilst the force devolved on the crank-pin by the reciprocating parts, in being retarded and brought to rest, supplements the falling pressure of the steam towards the end of the stroke. The resultant pressure on the crank-pin is indicated in the figure by the entire shaded portion, showing that the pressure on the crank-pin is approximately equalized from beginning to end of the stroke.

In Mr. Porter's description of the Allen Steam Engine,[1] he gives a diagram of the reciprocating pressures on the crank-pin. The cylinder is 12 inches in diameter, with a stroke of 2 feet, or a radius of crank of 1 foot. The weight of the reciprocating parts is 470 pounds, making 200 turns per minute, or 800 feet of piston. By the formula (4), page 86, the initial and final pressures or centrifugal forces are $(.00034 \times 470 \times 1 \times 200^2 =)$
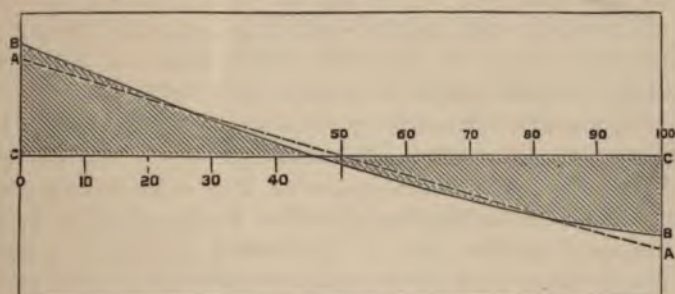

Fig. 453.—Equilibration of Steam Engines:—Accelerating and Retarding Forces—Mr. Porter's Diagram.

6411 pounds; or $(6411 \div 113$ (area of 12-inch cylinder)$=)$ 56.7 lbs. per square inch. The corresponding diagram of force is represented by fig. 453. The dotted line A A represents the pressure, supposing the angular movement of the connecting-rod to be neglected. The full line B B, slightly curved, represents the pressure, subject to the influence of a connecting-rod six times the length of the crank. The line C C is the datum line of zero or no pressure. It follows that under the given conditions steam of 56.6 lbs. effective pressure could be admitted suddenly to the cylinder at the commencement of the stroke without causing any shock or strain on the crank-pin. By the influence of the connecting-rod the pressure on the piston required to balance the inertia, instead of being 56.7 lbs. as above named, would be 66 lbs. at the outer end and 47½ lbs. at the inner end. Indicator diagrams from the engine are given by Mr. Porter, having the curve-line of resistance of parts inserted at the lower part of the diagrams. The advantageous mitigation of inequality of pressure on the piston is clearly exemplified.

That the resistance of inertia, or the centrifugal force of the reciprocating parts, which increases as the square of the speed, may be usefully enlisted for promoting smooth and steady working, it is obvious that relatively

[1] See his paper "On the Allen Engine and Governor," in the *Proceedings of the Institution of Mechanical Engineers*, April 1868; page 59.

high speeds should be practised. At low speeds the centrifugal resistance is comparatively trifling. It may also occasionally be expedient to add weight to the reciprocating parts in order to provide inertia resistance.

Quite independently of the equalization and moderation of stress on the crank-pin in the manner just discussed, there is the mass of the reciprocating parts to be counterbalanced. Such counterbalancing is demanded more especially in direct-acting high-speed engines. If done at all, it is done by applying counterweight or mass to the crank-shaft, in a sense opposed to the crank-pin; and it is conveniently effected by means of a loaded circular crank-disc. But practice varies as to the extent to which such counterbalancing is effected. In the case of horizontal direct-acting steam engines a perfect balance, in the horizontal sense, is effected by statically balancing the crank, crank-pin, and reciprocating parts as collected at the crank-pin, by a counterweight. But there is a want of balance by excess of counterweight, in the vertical sense, since the reciprocating parts do not all revolve, but are, with the exception of a portion of the connecting-rod, reciprocated in a straight horizontal line, involving the horizontal components but not the vertical components of circular motion. A compromise is therefore made; counterweighting is applied only to the extent of balancing the revolving parts, or it is extended to comprise so much of the weight of the connecting-rod as is supported by the crank-pin when on the dead centre. Mr. C. T. Porter compromised by counterbalancing about 60 per cent of the mass of the reciprocating parts, which, in the case of the engine constructed for the Edison steam-dynamo, to be afterwards noticed, comprised the weight of the connecting-rod, and fully one-half of the crosshead. Forty per cent was left unbalanced; but Mr. Porter found that the engine worked steadily. "This is not sufficient," he says, "to disturb the stability of the engine, while, on the other hand, the counterweight is not so great as to exert an objectionable strain in the vertical direction."[1]

It may seem paradoxical that, whilst equalization of pressure on the crank-pin and approximate uniform action are or may be effected in consequence of the inertia of the reciprocating parts, inertia should also be the cause of unsteadiness if the parts be not counterbalanced. In truth, the function of the counterweight is not to balance the stress at the crank-pin, but to counteract that portion of the steam-pressure on the cylinder-cover which is appropriated in getting up the speed of the reciprocating parts; and correspondingly also in bringing them to a state of rest. Thus, the counterweight acts supplementarily to the stress at the crank-pin, and the sum of the horizontal element of the centrifugal force of the counterweight and the stress at the crank-pin is equal to the effective steam-pressure on the cylinder-cover.

In vertical steam engines, the gravitation of the reciprocating parts plays a part in the disturbance of equilibrium. The function of the counter-

[1] See "Description of the Edison Steam Dynamo," by Messrs. Edison & Porter, in the *Transactions of the American Society of Mechanical Engineers*, vol. iii. 1882; page 222.

weight is not affected by this circumstance, as its gravity, also, is brought into play; but, in order to equilibrate the effective performance of the engine for the upward and downward strokes, in cases where the counter-weight is equivalent to only a fraction of the reciprocating parts, an adjust-ment of the valves is necessary in order that the work of the steam may be suitably greater in the upward stroke than in the downward stroke, to compensate for the alternate resistance and assistance of the unbalanced fraction of the reciprocating parts by their gravitation.

STATIONARY STEAM ENGINES FOR GENERAL PURPOSES.

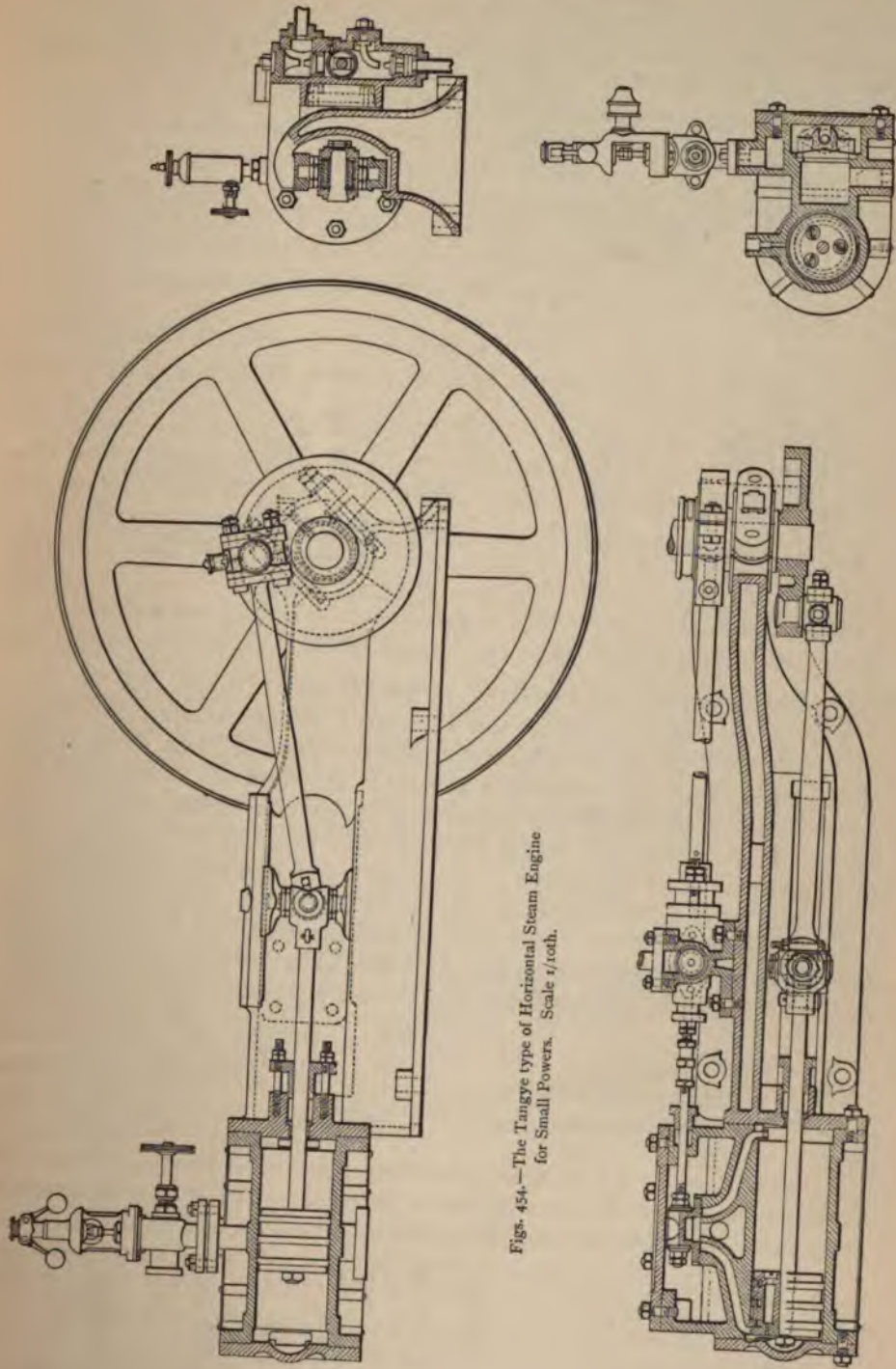## CHAPTER VII.—HORIZONTAL STEAM ENGINES.

CONSTRUCTED BY MESSRS. TANGYES, BIRMINGHAM.

I. HORIZONTAL STEAM ENGINE OF 2 NOMINAL HORSE-POWER.

(Cylinder 4 inches diameter, 8 inches stroke.)

The Tangye type of horizontal steam engine of the smaller powers, is shown by figs. 454, in which the frame, while supplying a wide base, combines with this the direct back connection supplied by the Corliss frame. The base extends from the face of the cylinder to and inclusive of the pedestal. The cylinder is overhung, and is bolted to and supported by the front cylinder-cover, which is cast in one with the frame. The guides for the crosshead and the pedestal also are cast in one with the frame and the cylinder-cover; and a continuous connection is made between the cylinder and the main shaft. The frame is a hollow casting, of great stiffness, well shown in section. It is held down to the foundation by five bolts,—two on each side, and one at the pedestal.

The cylinder is 4 inches in diameter, having 12.57 square inches of area, with a stroke of 8 inches, making 180 turns, or a speed of piston of 240 feet, per minute. It is not steam-jacketed. The steam-ports are $7/16$ inch wide and $2\frac{1}{2}$ inches deep, making an area of about $1/11$th of that of the piston. The slide-valve is driven by an eccentric keyed on the shaft. The piston-rod is fully $\frac{3}{4}$ inch in diameter. The fly-wheel is $2\frac{1}{2}$ feet in diameter, and 3 inches wide at the rim, the face of which is turned; the wheel weighs $1\frac{3}{4}$ cwts. The main shaft is straight, and is 2 inches in diameter, with a length of 28 inches. The steam-pipe is $\frac{3}{4}$ inch in diameter, or about $1/28$th of the piston in sectional area. The exhaust-pipe is $1\frac{1}{4}$ inches in diameter, having about $1/10$th of the area of the piston. The slides or guide-surfaces are flat, and the motion-blocks, of cast iron, are adjustable by double-nuts. The crosshead pin is 1 inch in diameter by $1\frac{1}{2}$ inches long, and is let into the crosshead with a taper head, and a nut at the other end. The connecting-rod is 1 inch in diameter at the ends, and $1^{3}/16$ inches at the middle; and is 20 inches in length, having five times the length of the crank. The crosshead brasses are fixed by a wedge with a nut at each end. The crank-pin end is fitted with a cap and two bolts. The frame, between the cylinder and the centre of the shaft, is 30 inches in length, of metal about $7/16$ inch thick. The centre-line of the cylinder is $6\frac{3}{4}$ inches above the level of the base. The pillow-block or pedestal is inclined at the angle $45°$ with the centre-line, and gives a bearing for the shaft 2 inches in diameter, and 3 inches long. The cap is fastened

Figs. 454.—The Tangye type of Horizontal Steam Engine for Small Powers. Scale 1/10th.

with two cotter bolts and nuts. The crank-pin is 1⅜ inches in diameter and 1¾ inches in length. It is fitted into and through a crank-disc, 10½ inches in diameter, keyed on the shaft, and riveted over. The governor, fig. 455, runs at 500 turns per minute. It is driven by bevel-gearing, and acts on a throttle-valve seated with the stop-valve, in one casting. It is fitted with a helical spring on the spindle to control the flight of the balls. The compression of the spring, and correspondingly the speed of the engine, are adjusted by a nut at the top of the spindle.
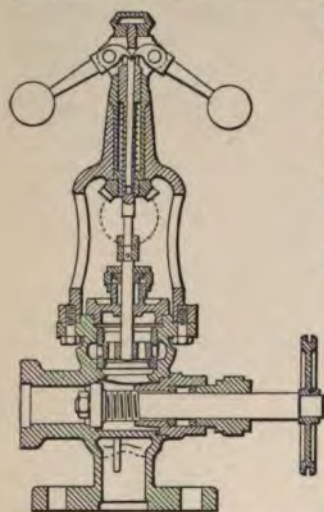
The feed-pump is fixed on the back of the frame, and is worked by the eccentric-rod,
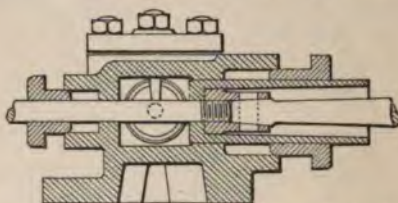

Fig. 455.—Tangye Governor. Scale 1/5th.

Fig. 456.—Feed-pump for Tangye Steam Engine for Small Powers. Scale 1/5th.

which also drives the valve spindle, in line, as shown in fig. 456.

Steam engines of the type now illustrated are manufactured of from 2 to 25 nominal horse-power, having cylinders of from 4 inches to 16 inches in diameter. For these diameters the areas are from 16 to 256 circular inches, respectively 8 circular inches and 10 circular inches per nominal horse-power. The prices (1884) are from £25 to £200, or from £12, 10s. to £8 per nominal horse-power. For an engine of 10 nominal horse-power there are 10 circular inches of piston-area, and the price is £10, 8s., per nominal horse-power. The costs of feed-pumps and holding bolts are in addition to the above-named prices. Variable-expansion gear is supplied extra for engines of 8 horse-power and greater powers:—

	2 H.P.	10 H.P.	25 H.P.
Feed-pump	£3	£7	£15
Holding-down bolts	£1, 5s.	£5	£8
Variable-expansion gear	—	£14	£25

Engines of from 10 to 25 horse-power are fitted with steam-jackets. In the following tablet (A) is a selection of particulars. These engines are also constructed in couples or pairs, being made right-hand and left-hand (B).

(B) Nominal horse-power	4	6	8	12	16	20	32	40	50
Diameter of cylinder....in.	4	5	6	8	9	10	13	14¼	16
Length of stroke......... ,,	8	10	12	16	18	20	24	28	28
Turns per minute	180	144	120	100	90	85	75	65	65
Price per pair	£50	68	80	126	160	208	290	350	400

(A) *Tangyes' Single Horizontal Steam Engines—2 H.P. to 25 H.P.*

| NOMINAL HORSE-POWER..........	2.	4.	8.	10.	12.	16.	20.	25.
Diameter of cylinder ......inches	4	6	9	10	11¼	13	14¼	16
Length of stroke........... ,,	8	12	18	20	20	24	28	28
Turns per minute..................	180	120	90	85	85	75	65	65
Speed of piston, in ft. per minute	240	240	270	283	283	300	303	303
Diameter of fly-wheel......inches	30	48	60	66	66	72	90	108
Width of rim of do........ ,,	3	5	7	8	8	9	10	12
Diameter of main shaft... ,,	2	2¾	3⅝	4	4¼	4½	4⅞	5⅜
Length of do......... ,,	28	30	48	51	54	54	63	72
Diameter of steam-pipe.. ,,	¾	1¼	1¾	2	2½	3	3½	4
Do. exhaust-pipe ,,	1¼	1¾	2½	3	3½	4	4½	5
Do. feed-pipes... ,,	½	1	1¼	1½	1½	1½	1¾	1¾
Weight of engine............cwts.	4½	9½	27½	35½	36	50	68	74
Do. fly-wheel.......... ,,	1¾	6¼	13	16	16	23	30	40
Engine and fly-wheel........ ,,	6¼	15¾	40½	51½	52	73	98	114

II. HORIZONTAL STEAM ENGINE—SOHO PATTERN, OF 10 NOMINAL HORSE-POWER.

(Cylinder 10 inches diameter, 12 inches stroke.)

In the Soho engine, self-contained, the main shaft is cranked, and has two bearings on the frame base-plate, one on each side of the crank. An engine of 10 nominal horse-power, figs. 457, has a cylinder which is not steam-jacketed, 10 inches in diameter, with a stroke of 12 inches, designed for a speed of 150 turns, or 300 feet of piston, per minute. The front cylinder-cover and the pedestals make one casting with the frame, and the cylinder is overhung. The distance from the centre of the cylinder to the centre-line of the crank-shaft is 55½ inches. The frame is looped to make room for the crank; and it has a continuous base or bearing on the foundation. It has two sides, 12½ inches high, formed with horizontal flanges at the top, which serve as slides for the crosshead-guides above the piston-rod. The slides are 7½ inches in length, and present a slide surface of 49 square inches. The crosshead and piston-rod work between the sides of the frame, at a level of about 8 inches above the base-level, measured to the centre-line of the piston-rod. The crosshead or motion-block pin is 1¾ inches in diameter and 4½ inches long. The crank-shaft is 3⅜ inches in diameter, and is bent to the shape. The pin or central bearing is 3¼ inches in diameter and 5 inches long. The journals are each 6¾ inches long. The journal brasses are parted at the angle 45°. Space is provided between the arms of the crank and each pillow-block to receive the valve-eccentric at one side, and the driving pulley for the governor at the other side. The eccentric-rod is of cast steel, double-flanged or of I section. It is carried straight to the valve-spindle, passing through an opening in the frame; and comparatively short steam-ways are obtained. The feed-pump is worked by a prolongation of the valve-spindle, at the back

of the valve-chest. The connecting-rod is 3 feet in length, or six times the length of the crank. It is of cast steel, of a double-flange or I section. It has a solid or closed end for the crosshead pin, with a wedge adjustment, and a cap with longitudinal bolts and nuts for the crank end. The fly-wheel is 50 inches in diameter, and 8 inches wide; it is keyed on the

Figs. 457.—Tangyes' Soho Steam Engine of 10 Nominal Horse-power. Scale 1/30th.
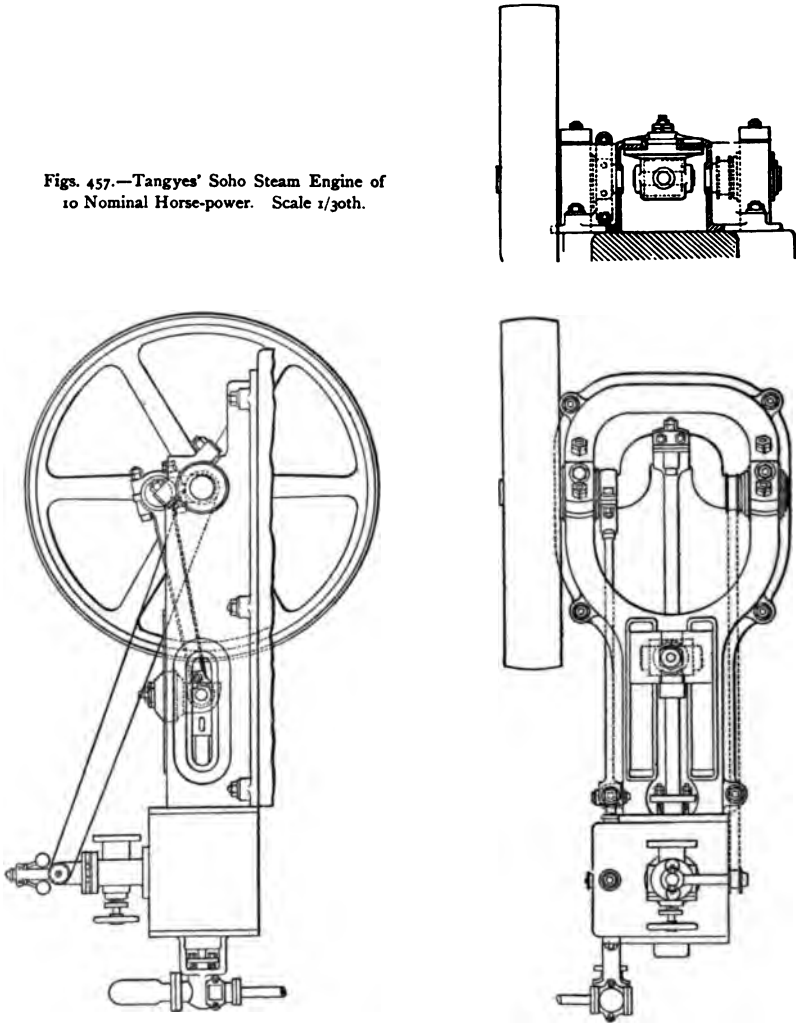
main shaft outside the frame. The steam-pipe is 2½ inches in diameter. The steam stop-valve is placed over the cylinder, and the governor over the stop-valve. The exhaust-pipe is 3 inches in diameter. The frame is secured to the foundation with six holding-down bolts and nuts. The extreme dimensions of the engine over all are 8 feet 5 inches by 4½ feet. The engine weighs 1 ton, and the price is £66, or £6, 12s. per horse-

power. There are 10 circular inches of area of piston per nominal horse-power. The feed-pump, as an extra, cost £4, and the holding-down bolts and plates, £2.

Tangyes' Soho Steam Engine—3 H.P. to 14 H.P.

NOMINAL HORSE-POWER............	3.	4.	6.	8.	10.	12.	14.
Diameter of cylinder ....inches	5	6½	8	9	10	11¼	12
Turns per minute......................	240	192	180	180	150	150	130
Diameter of fly-wheel..........inches	30	35	40	40	50	54	60
Width of rim of do.............. ,,	4	5	6	6	8	9	10
Diameter of main shaft .... ,,	2	2⅜	2¾	2¾	3⅜	3⅜	4
Do. steam-pipe........ ,,	1¼	1½	2	2	2½	2½	3
Do. exhaust-pipe...... ,,	1½	2	2½	2½	3	3	3½
Do. feed-pipes.......... ,,	1	1	1	1	1	1	1¼
Weight of engine, including fly-wheel..........................cwts.	4¾	7½	12½	12½	20	23	31

The areas of piston per horse-power, according to this tablet, are at the rate of about 10 circular inches per horse-power, except for the 3-horse-power engine, for which 8⅓ circular inches are allowed. The prices range from £25 for the 3-horse-power engine to £95 for the 14-horse-power engine, or from £8, 6s. 8d. to £6, 15s. 9d. per horse-power. These prices per horse-power range higher than those of the ordinary engine by Messrs. Tangyes, already noticed, page 92, arising from the fact that the strokes of the Soho engines are shorter than those of the others.

III. HORIZONTAL CONDENSING STEAM ENGINE, OF 50 NOMINAL HORSE-POWER.

(Cylinder 22¼ inches diameter, 40 inches stroke.)

Horizontal steam engines of large size are of the type shown in figs. 458. The cylinder, condenser, and pedestal are directly supported on the foundation, and the cylinder is connected to the pedestal by a girder frame,—in plan suggestive of a bayonet, and familiarly known as the bayonet frame.

The engine shown in the figures is of 50 nominal horse-power. The cylinder is 22¼ inches in diameter, with a stroke of 40 inches, and is steam-jacketed. The piston-rod is of steel, 3 inches in diameter. The engine is designed to run at a speed of 53 revolutions per minute, equivalent to a speed of piston of 353 feet per minute. According to these proportions, 8.3 circular inches of piston-area are allowed per nominal horse-power. The Meyer expansion-valve is employed, and the valves are worked by two independent eccentrics. The expansion-gear can be adjusted by means of a hand-wheel, while the engine is in motion, to cut off at any point of the stroke from 0 per cent to 75 per cent. The steam-pipe is 5½ inches in diameter, and the exhaust-pipe is 8 inches. The fly-wheel is 14 feet in diameter, and 24 inches wide at the rim, which is turned on the face. It has eight arms, and is cast in two halves, which are bolted

together with turned bolts at the centre and at the rim.   It weighs 6 tons.
The main shaft is of steel, 7¾ inches in diameter, and 7 feet 9 inches in
length.   The crank-journal is 10½ inches long, and the outer journal is
9½ inches long.   The crank-bearing is so arranged, in three pieces, with
wedge adjustment, that wear can be readily taken up.   The crank-pin is
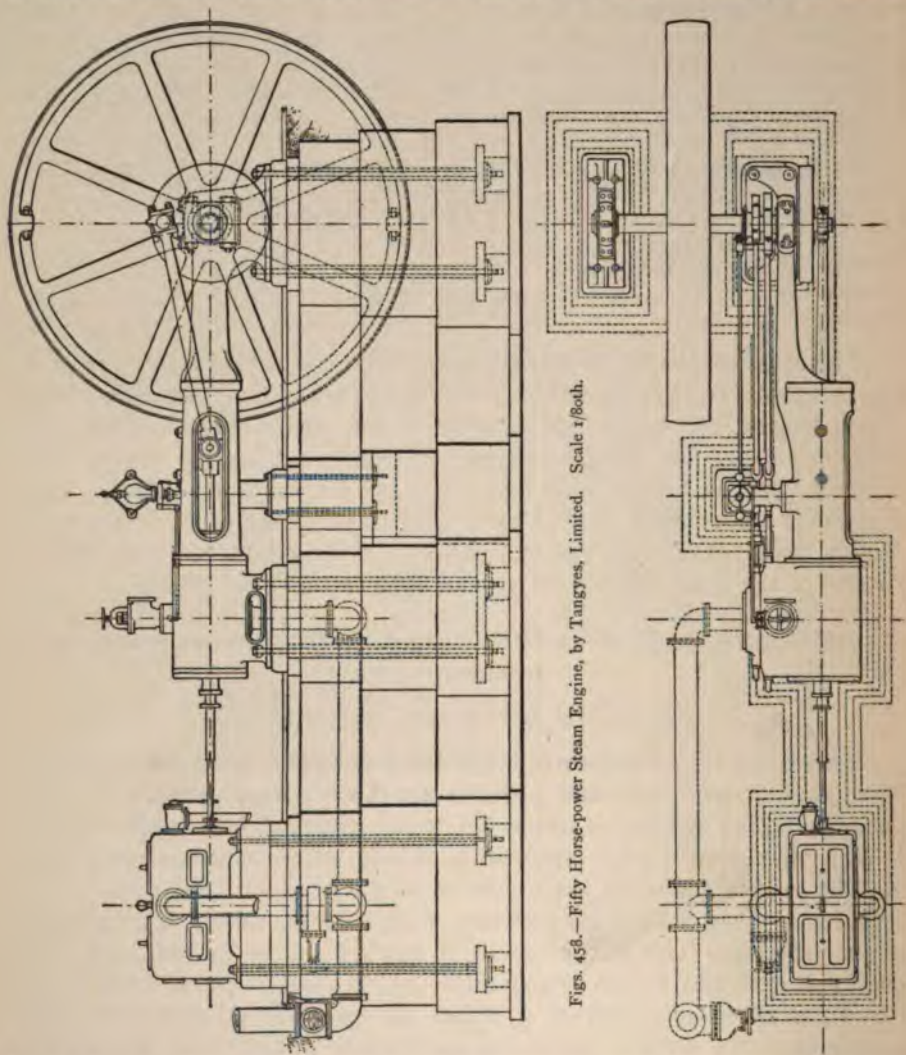
Figs. 458.—Fifty Horse-power Steam Engine, by Tangyes, Limited.   Scale 1/8oth.

keyed into a disc 4 feet 1½ inches in diameter, which is keyed on one end
of the shaft.   The connecting-rod is 8 feet in length,—nearly five times
the length of the crank, exactly 4.8 times.   It has a solid end with a single
bearing on the crosshead-pin, and is made with a cap and two longitudinal
turned bolts and nuts for the crank end.   It is 3½ inches in diameter at
the ends, and 4¾ inches at the middle.   The bearing of the crank-pin is
7 inches long.

The frame is a girder, in one casting with the front cylinder-cover and the pedestal; 11 feet 9 inches in length between the cylinder and the centre of the main shaft. It is formed cylindrical to join the cylinder, and is bored out to form guides for the crosshead. The remaining part of the frame towards the pedestal is hollow, where it is 15 inches deep and 7½ inches wide. The base of the crank pedestal is 4 feet long by 22 inches wide; that of the outer pedestal is 4½ feet long by 15 inches wide. The pedestals stand 2 feet 1 inch high; and are each secured by four 2-inch holding-down cotter-bolts and nuts. The cylinder also is held down by four 2-inch bolts.

The condenser and air-pump are placed behind the cylinder, in a line with it, the pump-rod being cottered to the piston-rod, which is prolonged to work through the back cylinder-cover. The air-pump is double-acting, and is so arranged with the condenser that the piston always works in water free from spaces wherein vapour can expand. The exhaust-pipe from the cylinder joins the condenser at the further side, the condensing water is introduced at the front, and the overflow water leaves by a pipe at the near side. The condenser is held down by four 1½-inch cotter-bolts and nuts. A feed-pump is not supplied as part of the engine, but as an auxiliary.

The speed of the engine is regulated by an ordinary Porter's governor driven by gearing from the crank-shaft. It is fitted with a dashpot, and is connected to a throttle-valve between the cylinder and the steam stop-valve.

The engine is placed on a foundation of brickwork, 8 feet 2 inches deep, under the floor-line. It is bedded on special blocks of stone below the cylinder, the pedestal, and the condenser.

The weight of the engine complete is about 14½ tons. Its extreme dimensions are 35 feet in length, and 10 feet 4 inches in width.

The price of the engine with condenser, not including a feed-pump, is £505, or about £10 per horse-power, or about £30 per ton. Holding-down bolts with plates cost £21 extra. The area of the piston gives about 10 square inches per horse-power. Engines of this type are constructed of from 30 to 60 horse-power.

The results of a trial made with this engine are recorded. The pressure in the boiler was 41 lbs. per square inch: reduced by throttling to 32 lbs. initial pressure in the cylinder; the vacuum in the condenser was 28¼ inches, and the speed was 45 turns, or 300 feet of piston, per minute. Steam was taken from a Lancashire boiler, consuming rough slack from Staffordshire pits, and the fuel was consumed at the rate of 2½ pounds per indicator horse-power. If it be assumed that 7 pounds of water was evaporated per pound of fuel, the equivalent consumption of water would be at the rate of $(7 \times 2\frac{1}{2} =)$ 17½ pounds per indicator horse-power.

If from want of injection-water, or from other cause, the engine is required to be worked without condensation, communication with the condenser is shut off by a sluice-valve; and it is opened by another sluice-valve to a

pipe through which the steam is exhausted into the atmosphere, as indi-
cated in the illustration, figs. 458.

Tangyes' High-pressure Condensing Steam Engines—30 H.P. to 60 H.P.

NOMINAL HORSE-POWER	30.	40.	50.	60.
Diameter of cylinder.........................inches	18	20	22¼	24½
Length of stroke............................. ,,	36	40	40	48
Turns per minute...................................	60	53	53	44
Speed of piston in feet per minute	360	353	353	352
Diameter of fly-wheel..........................feet	11	12	14	15
Width of rim of fly-wheel ....inches	12	22	24	26
Diameter of main shaft.................... ,,	6¾	7½	7¾	8½
Length of do. .... ,,	81	87	93	102
Diameter of steam-pipe..................... ,,	4½	5	5½	6
Do. exhaust-pipe...... .... ,,	6	7	8	9
Weight of engine, with fly-wheel ....tons	9	13	14½	21½
Do. fly-wheel only .... ,,	2¼	5	6	8

CHAPTER VIII.

HORIZONTAL CONDENSING STEAM ENGINE.

CONSTRUCTED BY MESSRS. EASTON & ANDERSON, ERITH AND LONDON.

PLATE IV.

(Cylinder 27 inches diameter, 36 inches stroke.)

A group of four horizontal condensing single-cylinder steam engines
were, in 1875, arranged for the service of the Imperial Docks at Cronstadt,
in pumping out water.

A large bevel-wheel is fastened on the back of the fly-wheel of each
engine, from which, by the medium of a smaller bevel-wheel on an upright
shaft, motion is given to a centrifugal pump or fan at the bottom of a well,
for the extraction, elevation, and discharge of water.

One of the engines is represented in elevation and plan in Plate IV.
The cylinder and the condenser with the air-pump are placed in line, on
a continuous cast-iron bed, with the main shaft and pedestals at the other
end. The crank end of the shaft is supported on the bed, and the outer
end is supported on a separate bearing.

The bed is fastened to the foundation with nine 1¾-inch holding-down
bolts.

The cylinder, figs. 459, 461, and 462, is 27 inches in diameter, with a stroke
of 3 feet. It is steam-jacketed at each end, but not on the barrel. At normal
speed, the engine makes from 70 to 75 revolutions, or from 420 feet to 450 feet
of piston per minute for maximum lift, with a pressure of 60 lbs. per square
inch in the boiler. The barrel is 1¼ inches thick; so also are the flanges;
and the barrel is strengthened by a strip at the centre, and at each flange,

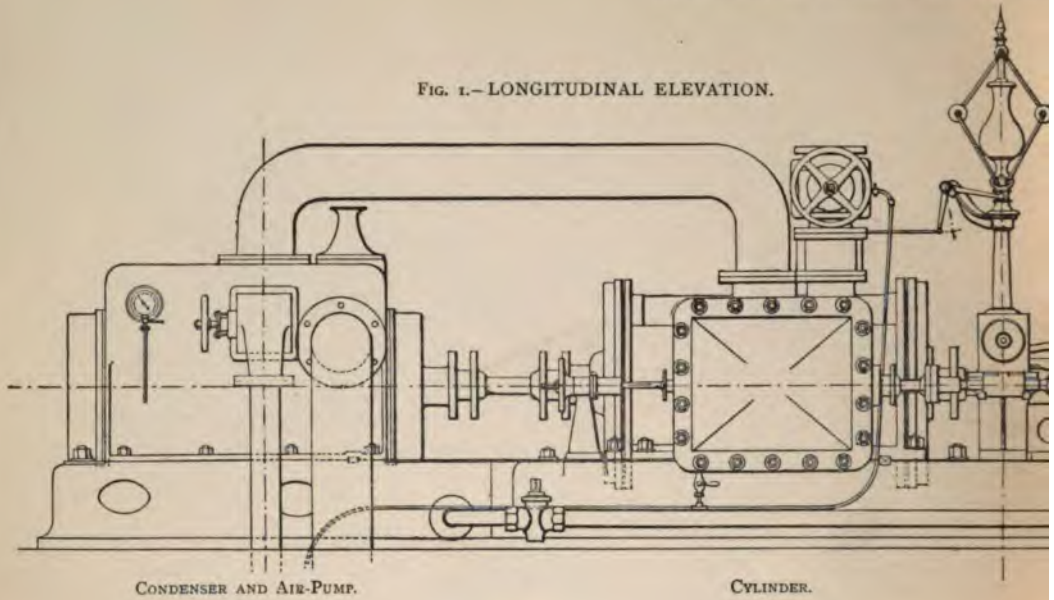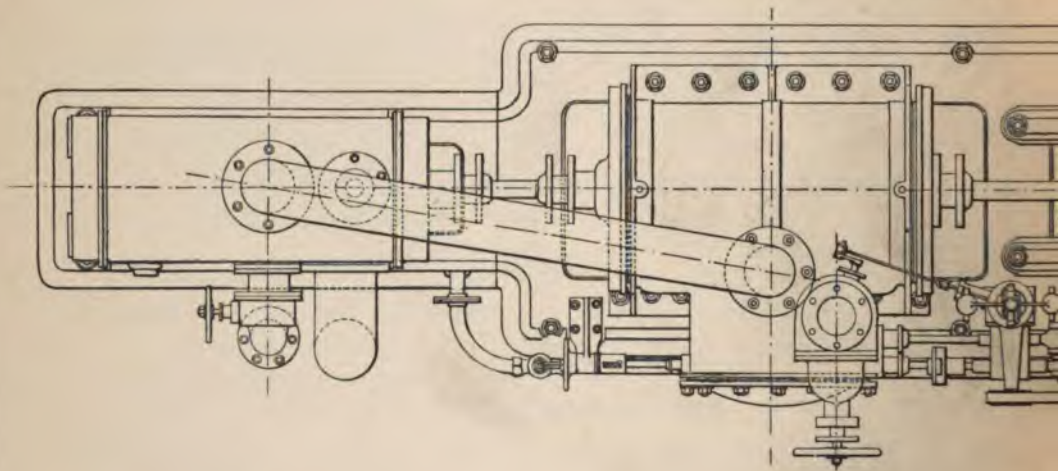FIG. 1.—LONGITUDINAL ELEVATION.
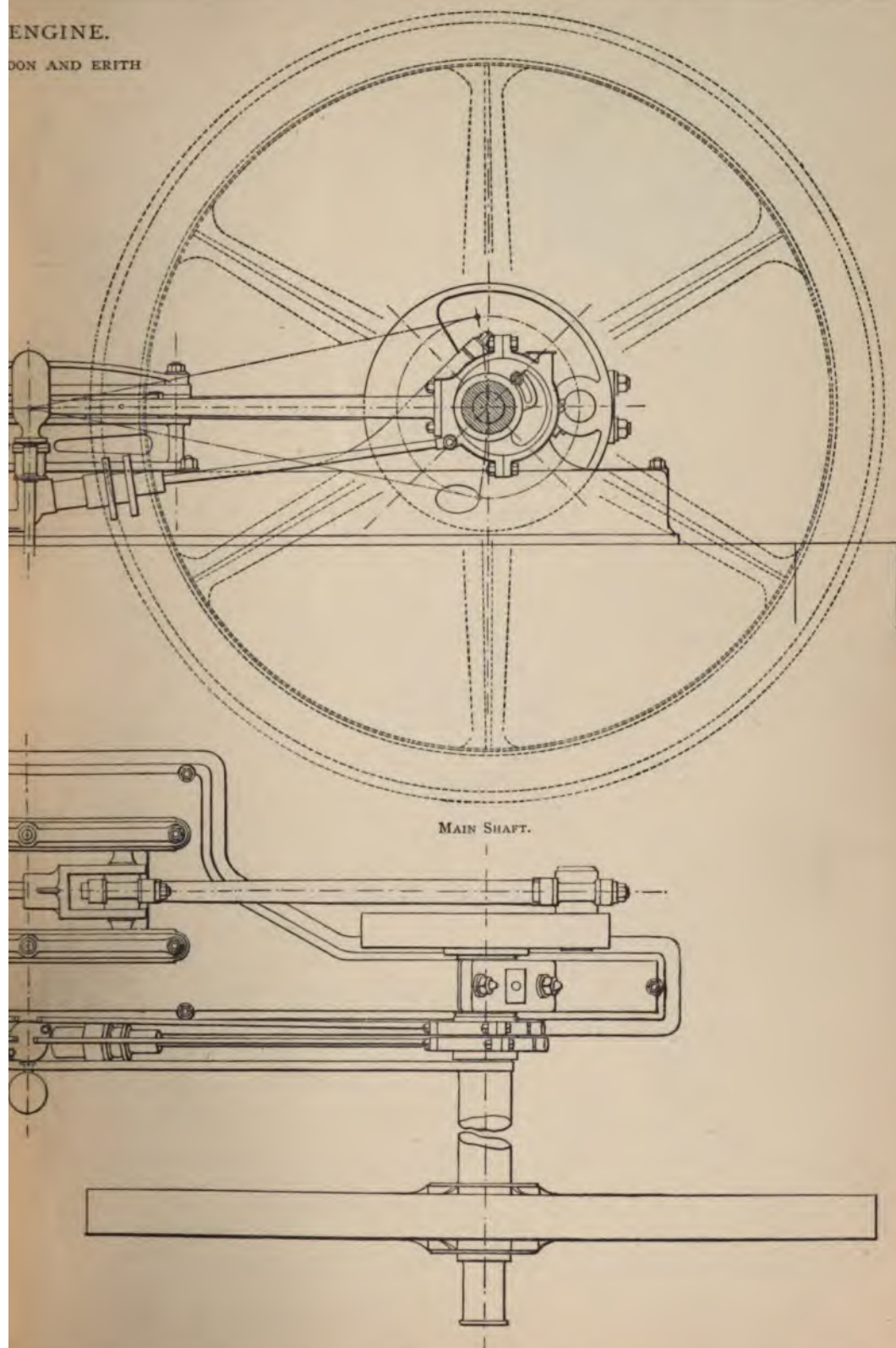
CONDENSER AND AIR-PUMP.

CYLINDER.

FIG 2.—PLAN.

Diameter of Cylinder, 27 in.
Stroke of Piston, 36 in.
Speed, from 70 to 75 Revolutions per minute.
Diameter of Air-Pump, 14 in.
Diameter of Main Shaft, 10½ in.
Diameter of Fly-wheel, 13 ft.; weight, 6 tons.
Total weight, 19 tons.

Scale 1-32nd, or ⅜ inch = 1 foot.

PLATE IV.

ENGINE.

DON AND ERITH

MAIN SHAFT.

where it is 1½ inches thick.   The cover at each end is cast hollow, or double, to hold the jacket-steam.   It is ¾ inch thick for the inner and outer faces.

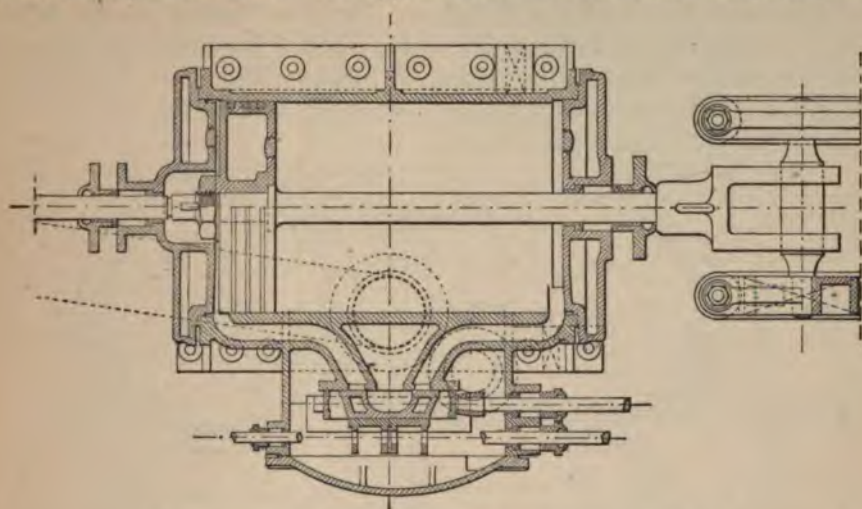Fig. 459.—Easton & Anderson : Cylinder. Horizontal Section. Scale 1/24th.

Each cover is bolted to the cylinder with twelve 1⅛-inch bolts and nuts pitched at about 8½ inches.   The steam-ports are 2⅛ inches long by

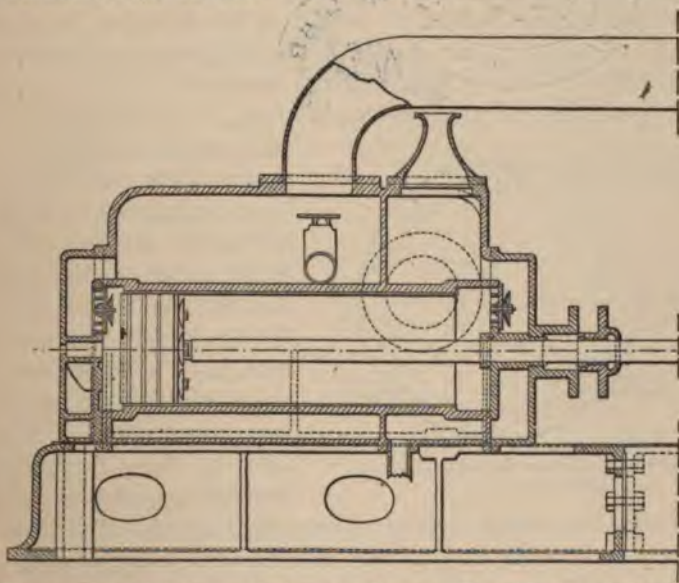Fig. 460.—Easton & Anderson : Condenser and Air-pump. Vertical Section. Scale 1/24th

18 inches wide,—having an area $\frac{1}{10}$th of that of the cylinder.   The exhaust-port is 3 inches long.

The valve-chest is of ⅞-inch metal.   The cover applied in front is of

cast-iron, ¾ inch thick; it is groin-arched, with a rise of 4 inches, and has a middle rib or flange, longitudinally, 1 inch thick, to prevent the valves from leaving the face of the cylinder. The joint flanges of the valve-chest and cover are 1¼ inches thick, and are bolted together with eighteen 1-inch bolts and nuts at 6 inches of pitch. The main-slide valve, figs. 463, is double-ported for steam; having ¾ inch of lap and ⅛ inch
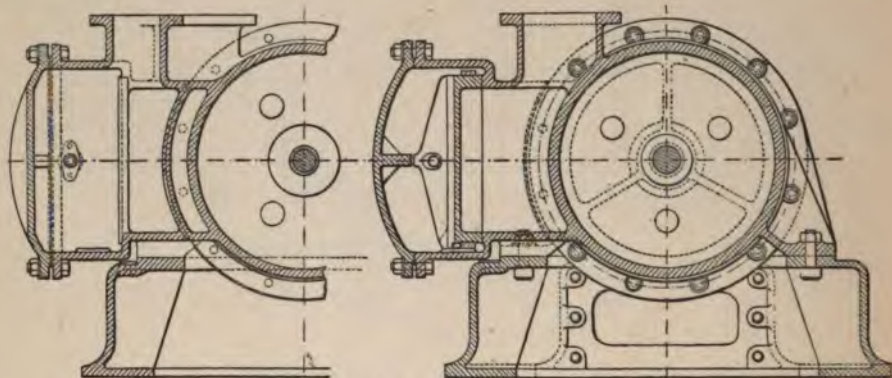
Figs. 461.—Easton & Anderson: Steam-cylinder. Scale 1/24th.

inside lap. An expansion-valve, on Meyer's system, consisting of two plates with right-and-left-hand adjusting screws, works on the back of the main-valve, with 6 inches of travel; it is adjustable for cutting off at from ¼th to ⅝ths of the stroke. The diagram, fig. 464, represents the several paths of the crank and the eccentrics, with the respective angles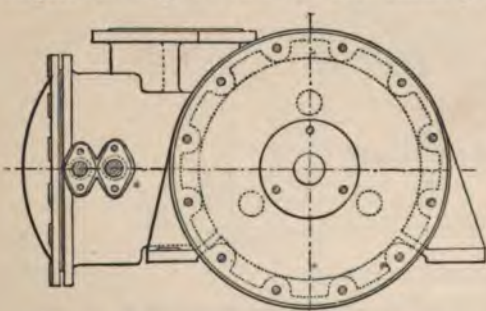 and positions of the crank-pin and the centres of the main and cut-off eccentrics for the three leading points of the stroke: —at the beginning, at ¼ stroke, and at ⅝ stroke. The centres of the crank-pin, the main eccentric, and the cut-off eccentric, at the beginning of the stroke are at A, B, C; at ¼ stroke, they are at A′, B′, C′; and at ⅝ stroke, they are at A″, B″, C″. The relations of these positions to the proportions and movements of

Fig. 462.—Easton & Anderson:—End view of Cylinder. Scale 1/24th.

the valves can be readily traced:—bearing in mind that the vertical centre-line D E represents the positions of the valves when at half-travel.

The spindles of the main valve and the cut-off valve are of steel. They are respectively 1¾ inches and 1½ inches in diameter, and are 4¼ inches apart. The main spindle is cottered to a rectangular frame of wrought iron embracing the main valve; 2 inches deep, and ¾ inch thick at each side. At the front and back the frame is 1 inch thick at each corner,

thickened to 1⅝ inches at the middle of the front, where it is cottered to the spindle; and to 1½ inches at the middle of the back. The cotter is 1¼ inches by 7/16 inch thick, rounded at the edges. The right-hand and left-hand screws on the cut-off spindle are square-threaded, of ¼ inch pitch, and are each 6 inches long. The right-hand screw is next the front of the chest, and is 1½ inches in diameter; the left-hand screw is 1¼ inches in diameter, or ¼ inch less than the other, that the front half-valve may be passed over it, to reach the front and larger screw. The spindle is prolonged through the back of the valve-chest, 1 inch in diameter; and, for a length of 9½ inches at the end, it is reduced to the inscribed square, by which it can be turned for the adjustment of the valve. This is done by means of a small hand-wheel, fixed on a brass sleeve, which fits the square end of the rod, and permits of its reciprocating. The inner end of the sleeve is screwed on the outside, and carries a nut to which a pointer is attached, to show the point of cutting-off. The valve-spindles pass through stuffing-boxes at the ends of the valve-chest; and are, in addition, stayed by guides 7 inches long, through which they reciprocate, side by side. The spindles are enlarged to 1⅞ inches and 1¾ inches in diameter respectively
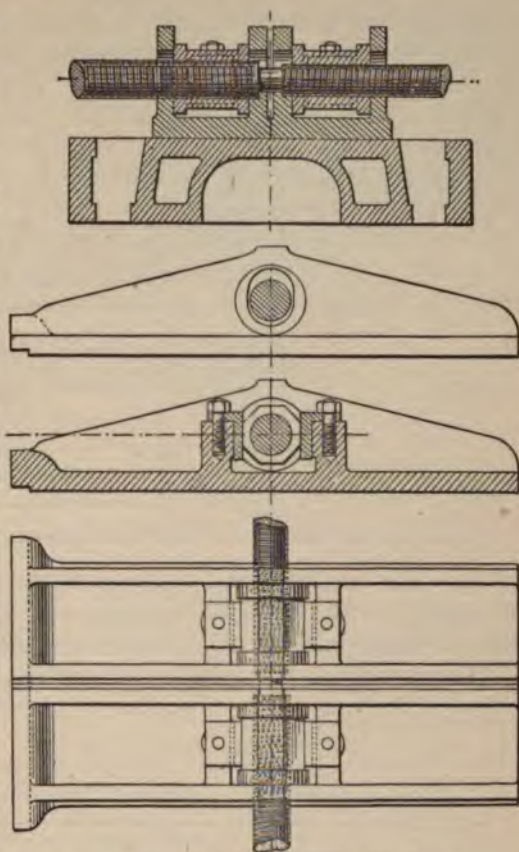
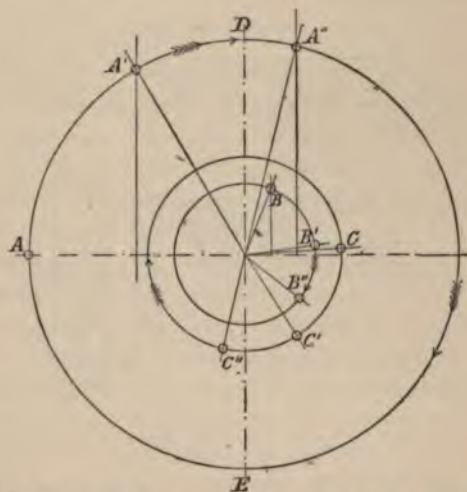Figs. 463.—Easton & Anderson: Main-slide and Meyer Cut-off Valves.   Scale 1/8th.

Fig. 464.—Easton & Anderson: Diagram for setting Eccentrics and Slide-valves.

at the guides.   To admit of the revolution of the cut-off spindle, for adjust-
ment, it is formed with a swivel joint, between the stuffing-box and the
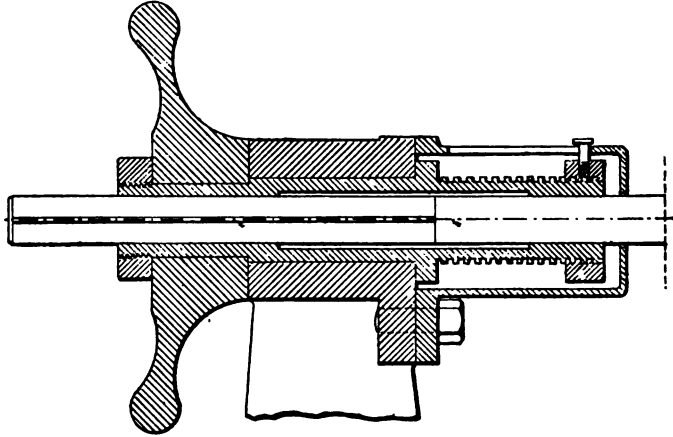
Fig. 465.—Easton & Anderson: Hand-wheel for adjusting Meyer Expansion Valves. Scale 1/4th.

guide. The end of each spindle is formed as an eye, bushed with brass.
The main spindle takes a 2-inch pin, and the eye is $3\frac{1}{4}$ inches wide.   The
cut-off spindle takes a $1\frac{3}{4}$-inch pin, and the eye is $1\frac{1}{2}$ inches wide.
   .The eccentrics, figs. 466, are of cast iron, in two pieces fixed together by
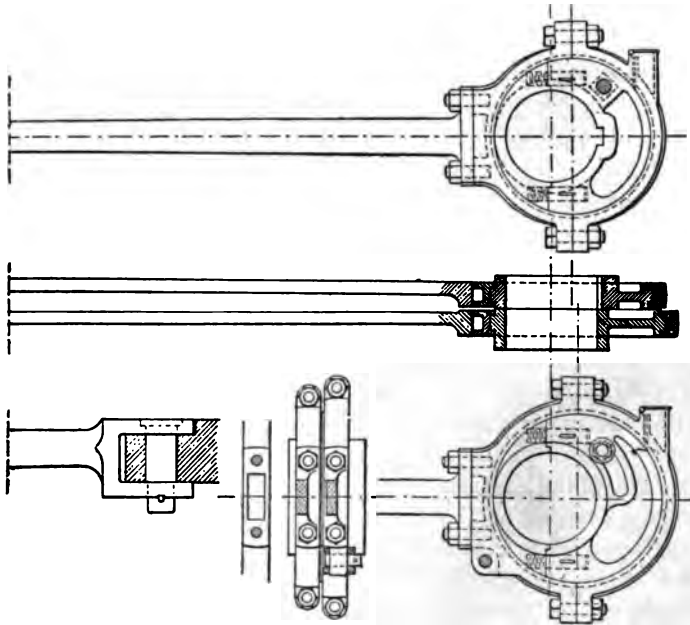
Figs. 466.—Easton & Anderson: Eccentrics, Straps, and Rods. Scale 1/16th.

screws.   They have $10\frac{1}{2}$ inches bore to fit the main shaft, and are $2\frac{7}{8}$ inches
wide at the rim.   The rims are notched down $\frac{1}{2}$ inch at each side to give

lateral hold to the straps.   These are 2¾ inches wide, and are formed each
with a flat face 1¾ inches wide by 11 inches to join to the rods.   The main
eccentric is 18½ inches in diameter; and the nave is 3¾ inches long.   The
eccentric is keyed fast on the shaft.   The eccentric-rod has a flat palm, by
which it is fastened to the eccentric-strap with two 1¼-inch stud-bolts and
nuts.   The strap and rod together are 9 feet 3 inches long between centres.
The rod is 1⅜ inches thick, and tapers from 4 inches deep at the strap to
2½ inches deep at the end.   It is forked and jointed to the valve-spindle
with a 2-inch pin, as before stated.   The cut-off eccentric is 20 inches in
diameter, and the nave is 4½ inches wide.   The rod is fastened similarly to
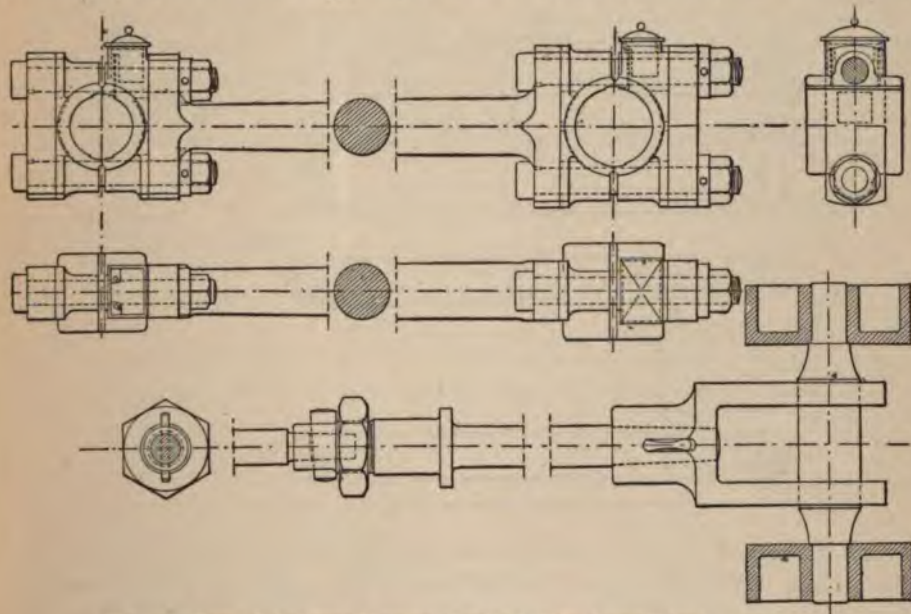
Figs. 467.—Easton & Anderson: Piston-rod, Crosshead, Slides, Connecting-rod.   Scale 1/16th.

the other rod; and the length of the rod and the strap together, between
centres, is 9 feet 2¾ inches.   The rod is 1¼ inches thick, and tapers from
4 inches deep at the strap to 2½ inches at the end, where it is forked to
take the eye of the spindle.   The cut-off eccentric is not keyed on the
shaft; but is held in place by a 1½-inch bolt and nut fastened to the main
eccentric, in a slotted groove which permits of adjustment.

Steam is supplied to the cylinder by a 6-inch cast-iron pipe, fitted with
a 6-inch steam sluice-valve, and a 6-inch throttle-valve below it, bolted to
the valve-chest, controlled by the governor.   A ¾-inch pet cock is screwed
into the sluice-valve case, to let off condensation-water which is conducted
away by a small tube, with which a junction from the valve-chest is made.

The steam supply for the four engines is brought in a 12-inch main,
from which a 7½-inch pipe branches to the right, and one to the left.   Each
of these is branched into two 6-inch pipes, one connected to each engine.

The piston (see fig. 459, page 99) is 7 inches wide, in one casting,

hollow, having the sides ⅞ inch thick.   The rim is 1⅜ inches thick, and is grooved for three packing rings on Ramsbottom's system, ½ inch wide and ⅜ inch thick.   The nave is bored to 4½ inches in diameter for the piston-rod, round which there is 1½ inches of thickness of metal.   The piston-rod, figs. 459 and 467, is of steel.   It is 3½ inches in diameter, except in the piston, where it is 4½ inches, with a 6-inch collar let flush into the piston, screwed up with a wrought-iron nut 2½ inches thick, at the back; except also a short prolongation beyond the nut, 3¾ inches in diameter, bored out to receive the end of the air-pump rod.   The other end of the piston-rod is tapered for a length of 9 inches, from 3⅜ inches, forming a slight shoulder with the
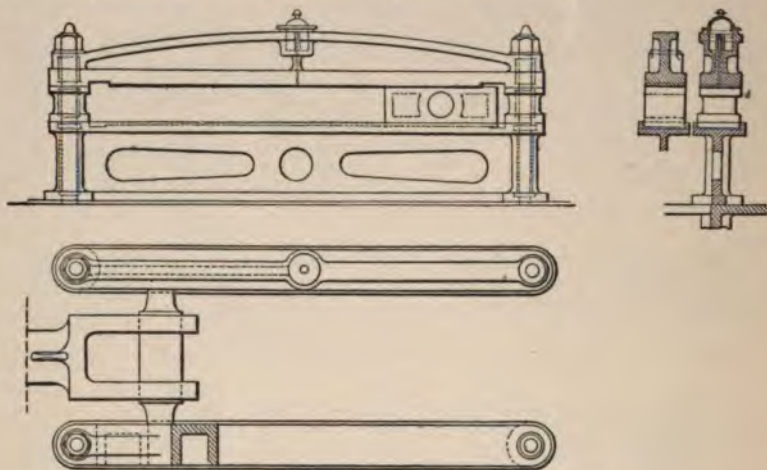
Figs. 468.—Easton & Anderson: Guide-bars.   Scale 1/24th.

body of the rod, to 2⅝ inches at the end, following a taper of 1 inch per lineal foot.   With this taper it is fastened in the crosshead, with a wrought-iron cotter 1 inch thick, 9 inches long, by 4¼ inches wide at the top, tapered to 4 inches wide at the lower end, where it is prevented from starting by a round pin put through it.   The total length of the piston-rod is 5 feet 10⅜ inches.   The crosshead is of wrought iron.   It is forked, and is 6½ inches wide between the forks.   The pin is 5¼ inches in diameter, and is reduced to 3 inches at each end, to take into the slide-blocks.   The forks of the crosshead are 2 inches thick by 6½ inches deep; and they are 9¼ inches in diameter round the pin, making a section of metal 2 inches square round the pin.   The socket is 9 inches long and 6½ inches in diameter, giving a mean thickness of 1¾ inches of metal round the piston-rod.   The guide-blocks are of cast iron.   They are each 5 inches wide by 5 inches deep, and 14 inches long; hollow, of 1 inch thickness of metal. They are 17 inches apart, transversely.   The guide-bars, of cast iron, detailed in figs. 468, are, like the guide-blocks, 5 inches wide; with the addition of a ½-inch ledge at each side of the lower bars, partly as checks to keep the blocks in place, and partly to contain the lubricant.   The lower guide is a regular double-flanged girder, uniformly supported, 9 inches deep,

of which the upper flange—providing the sliding surface—is 1 inch thick. The upper guide is a beam, only 6½ inches deep at the middle, supported at the ends only, and therefore it has the lower flange 1¾ inches thick. The span of these bars or beams is 4¾ feet between the centres of the 1¾-inch bolts and nuts, by which they are held to the base.

The connecting-rod, figs. 467, page 103, is of wrought iron, 7½ feet long between centres, or 5 times the length of the crank. The bearings at each end are of the cap-and-bolts construction, with flat faces and brasses between, having two bolts and collar-nuts of soft steel for the smaller end, and wrought iron for the larger end. Soft steel was adopted for the small-end bolts to minimize the size. The collar-nuts are secured by a set-screw to each nut. The inner surface of the brasses is recessed at the top and the bottom for a width of 2 inches, or 1 inch off each brass. A rectangular oil-cup is cast with one of the brasses, having two capillary conduits for oil, one to each end of the journal. The respective dimensions of the ends are as follows:—

	Crosshead End. inches.	Crank-pin End. inches.
Diameter of bearings	5¼	6½
Length of do.	6½	8
Thickness of butt and cap	2½	2½
Width of do. do.	4¼	5
Length of do. do.	12¼	13¾
Distance apart of the butt and cap, occupied by the brasses	8	9
Thickness of metal of brasses round the journals	1⅛	1
Do. do. do. round the bolts	½	½
Diameter of bolts and collar-nuts	2	2¼
Thickness of heads of bolts	1½	1½
Diameter of do. do.	3	3¼
Thickness of collar-nuts	2¾	3
Inside length and width of oil-cup	2⅞ × 3¾	3 × 4½

The body of the connecting-rod is round, and is cylindrical for the half length next the larger end, 4¾ inches in diameter. From the mid length it tapers to 3¾ inches in diameter at the smaller end.

The main shaft, figs. 469, is of wrought iron, 10½ inches in diameter, turned throughout. It has two journals, each 12 inches long, of which the neck journal is 9½ inches in diameter, and the outer journal is 8 inches in diameter, with a collar at the end 9½ inches in diameter and 1 inch thick. A crank disc, of cast iron, 4 feet 1 inch in diameter, is shrunk on and keyed on the end of the shaft, with a 1¼-inch round steel pin. The nave of the disc is 8¼ inches long and 18½ inches in diameter, having 4 inches of metal round the shaft. The rim is 7¼ inches wide, and the face or web of the disc, with the rim, are 1½ inches thick. The crank-pin is of wrought iron, 6½ inches in diameter, let with a thin collar into an eye on the disc, 7 inches deep, with 2½ inches of metal round the pin. It is shrunk in and fixed in place by a wrought-iron cotter, 2½ inches by

1¾ inches, 15½ inches in length, tapered at the rate of ¼ inch per foot. The cotter is secured by a split pin passed through the smaller end. The journal is 6½ inches in diameter and 8 inches long, having a collar at the end, 7½ inches in diameter and ¾ inch thick. The eye for the crank-pin is connected direct to the central nave of the disc by a short arm, 5 inches
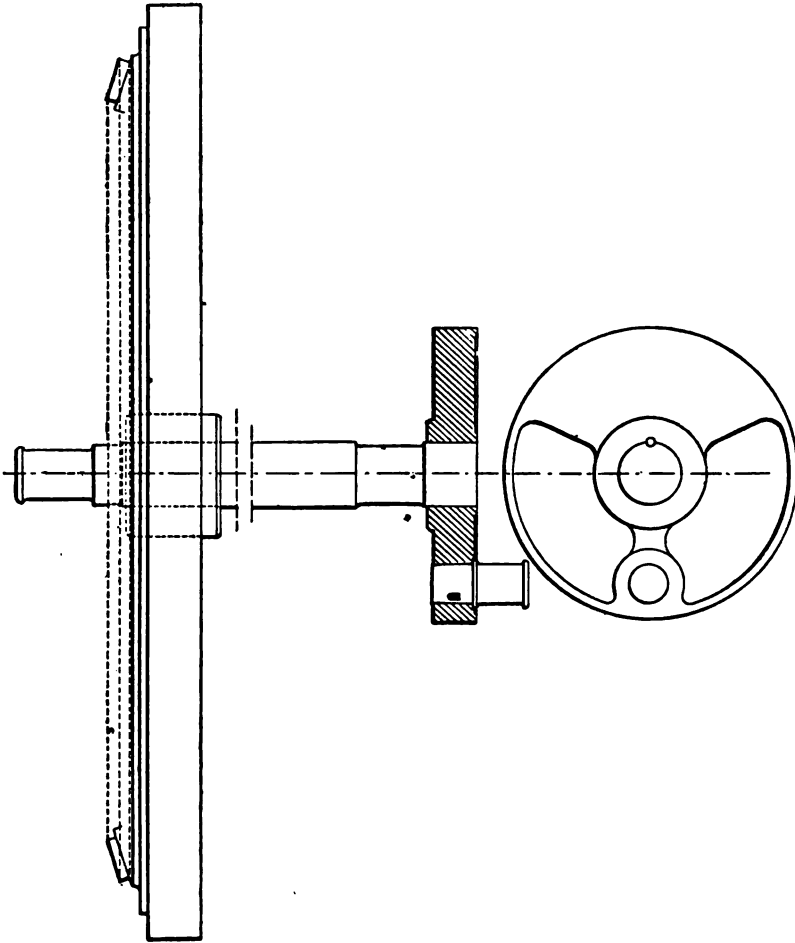
Figs. 469.—Easton & Anderson: Main Shaft, Crank Disc, and Fly-wheel.   Scale 1/32d.

wide, cast solid with the disc. The disc is heavily counterweighted to balance the crank and part of the connecting-rod, as shown.

The fly-wheel, figs. 469 and 470, is of cast iron, 13 feet in diameter, with six arms. It is in halves, joined at the centre and the rim. The centre or nave is 1 foot 11 inches in diameter, by 16 inches deep. It is hollow, having a cavity 20 inches in diameter and 7 inches wide, leaving 4½ inches of solid metal bearing on the shaft at each side. It is bored to 10½ inches in diameter to fit the shaft, on which it is keyed by one steel key 2⅝ inches wide. The halves are fitted and united by four 2½-inch iron bolts and

nuts, to give bearing for which the nave is formed up with parallel sur-
faces 22 inches apart. The bolts are 15 inches apart across the shaft, and
10½ inches apart parallel to the shaft. The rim is rectangular in sec-
tion, 8¾ inches wide at the circumference, by 10 inches deep radially,
panelled at the sides; faced at the edges of the outer circumference, and
on the outer face to receive a bevel-wheel, or more properly a circular
bevel rack or "geared ring," for taking off the power. Each of the two
joints of the rim is made with a wrought-iron dowel-pin, 3 inches square,
19½ inches in length, fastened with two cotters 3¾ inches by 1 inch, one to
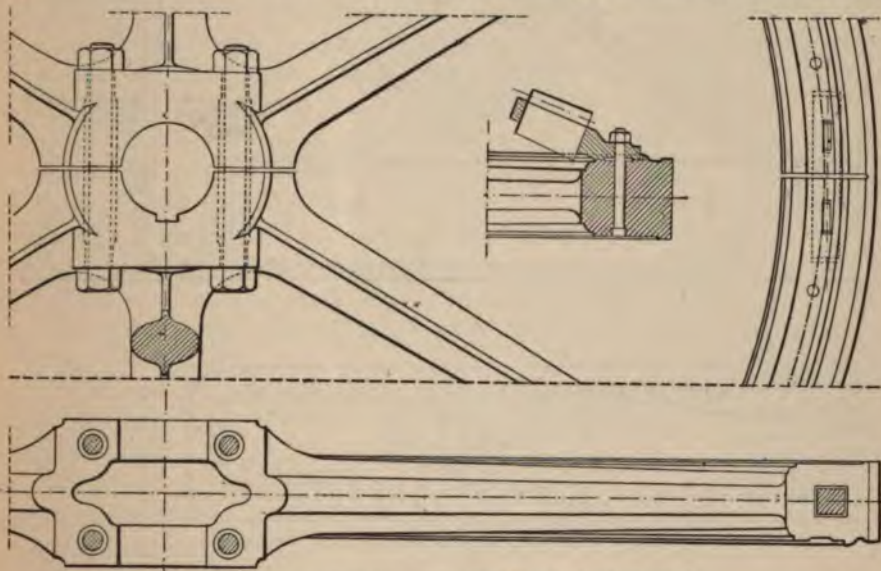
Figs. 470.—Easton & Anderson: Detail of Fly-wheel. Scale 3/64ths.

each segment. Square holes for barring are formed in the outer surface
of the rim, 4 inches apart. They are two inches square at the surface,
tapered to 1⅝ inches at the bottom and 1¼ inches deep. The arms are
straight and radial, oval in section, 5 inches by 8 inches at the centre,
tapered to 4 inches by 6 inches at the rim. They are stiffened by a low
flange on each side, 1½ inches thick at the centre, tapered to 1 inch at
the rim.

The bevel-geared ring is mortised, and is 11 feet 5 inches in diameter,
fastened with a flange 12 feet 5 inches in diameter to the rim of the fly-
wheel, by eighteen 1⅛-inch bolts and nuts, with countersunk heads. A
horizontal bevel-wheel, 3 feet 5 inches in diameter, is geared to the ring,
on a vertical shaft, to the lower end of which a centrifugal pump is fixed.

The main pedestal, figs. 471, is cast with the bed. It is sloped to the
angle 45°. The brass bearing is 9½ inches in diameter and 12 inches long,
in halves, parting on the angle, ¹¹/₁₆ inch thick all round the bearing.
Between the sides of the pedestal, 12⅞ inches apart, the cap is inserted.
It is 10 inches wide, 23 inches long, and 2¾ inches thick for the bolt-holes.

It is fastened by two 2¼-inch iron bolts and collar-nuts to the pedestal.
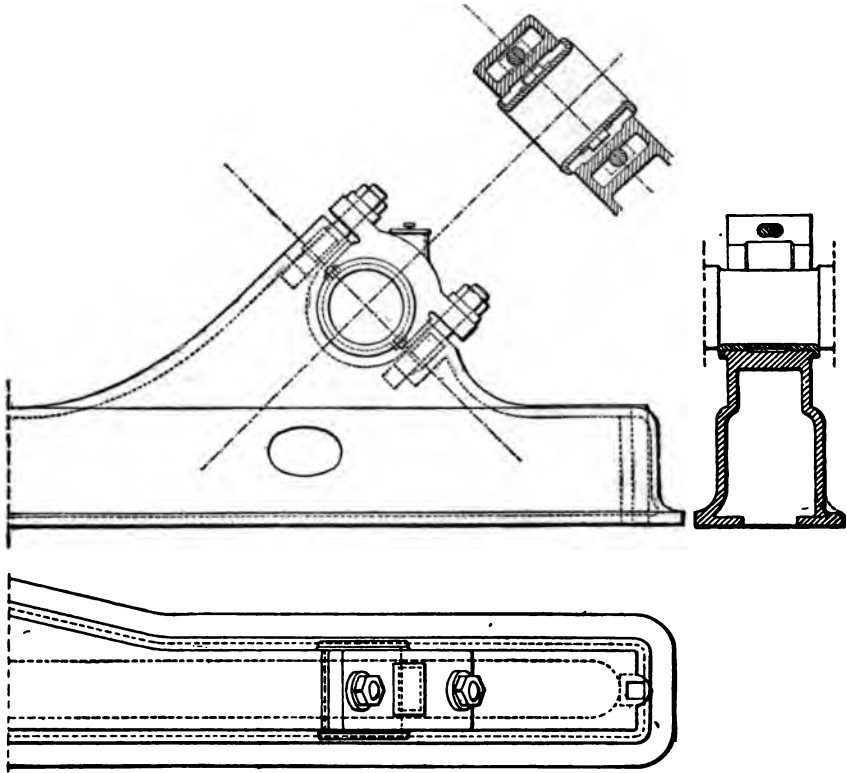
Figs. 471.—Easton & Anderson: Main Pedestal. Scale 1/24th.

The bolts are got into place by being passed through a hand-hole in the
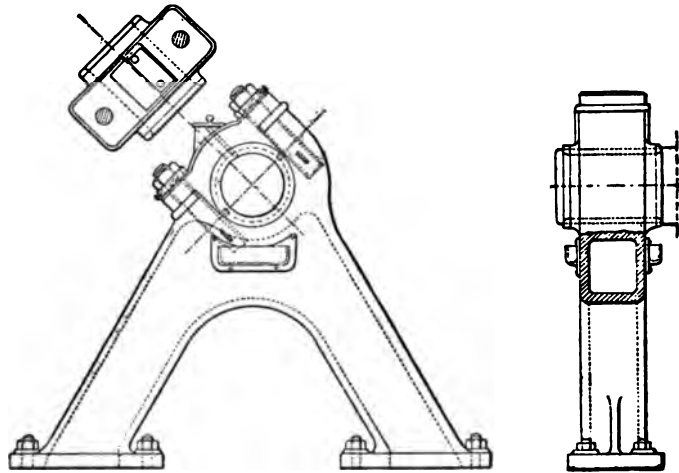
Figs. 472.—Easton & Anderson: Bracket to carry Outer End of Main Shaft.   Scale 1/24th.

side of the bed, shown in the figure; the nuts are secured in place by a

½-inch set-screw to each. A rectangular oil-box of brass is fixed on the cap, 6¾ inches by 4 inches outside measure, lubricating by two wicks.

The pedestal for the outer bearing of the main shaft is shown in figs. 472. The bearing is inclined at the angle 45°. It is 8 inches in diameter and 12 inches long. The pedestal is of cast iron, triangular in form, on two inclined limbs, which are hollow, being 9 inches wide by 8 inches in section, and of 1-inch metal, and are terminated each by a flange base, 12 inches by 19 inches, and 2 inches thick, bolted down to a cast-iron beam with four 1¼-inch bolts and nuts, and secured with a key at each end of each base, 2 inches by ¾ inch. The pedestal stands 3 feet high above the beam, on a total base 5 feet long over the flanges. The cap is fastened with two

Fig. 473.—Easton & Anderson: Condenser. Scale 1/24th.

2-inch cotter bolts and collar-nuts, the cotters being 2 inches by ½ inch, and the nuts being secured by ½-inch set-screws. A brass oil-box is fastened on the cap, with passages for the wicks. A brass trough, 9 inches long, is fixed on the pedestal at each side, beneath the bearing, to collect stray oil.

The condenser, fig. 460, p. 99, and fig. 473, is a cast-iron case, 4 ft. long, 24½ inches wide, semicircular in form at the lower side, and 2 ft. 9 in. high, outside measure, of ¾-inch metal, thickened to 1¼ inches at junctions. The steam is exhausted from the cylinder into the condenser at the top through a copper pipe, 9 inches in diameter. Condensing water is

Figs. 474.—Easton & Anderson: Details of Condenser. Scale 1/12th.

conducted through a 5-inch cast-iron pipe, ½ inch thick, and delivered through the front of the condenser, into a conduit of rectangular section 6 inches wide by 3 inches, of sheet copper, No. 12 wire-gauge in thickness,
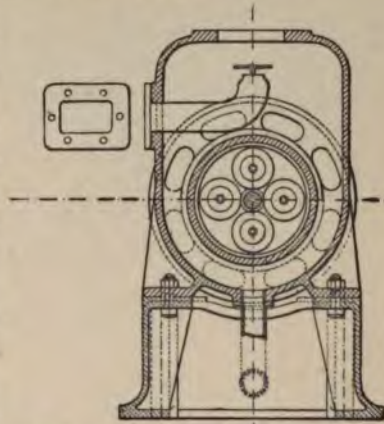
as detailed in figs. 474. The end of the pipe is turned upwards to face the entering exhaust steam, and is of the reduced rectangular section, 4 inches by 3 inches. It is surmounted by two brass discs, one above the other, acting as baffle-plates, to break up and disperse the stream of water. A regulating sluice-valve is applied to the entrance to the condenser, 7½ inches wide, having ¾ inch of lap at each side. It is moved by a small pinion $1^{15}/_{16}$ inches in diameter, having 12 teeth of ½-inch pitch and 1½ inches wide, gearing into a rack of 10 teeth cast on the back of the sluice. The pinion is turned by a hand-wheel 8½ inches in diameter, graduated and fitted with a pointer to show the extent of opening of the sluice. The sluice-case is of cast iron, ½ inch thick, fixed to the condenser with six ⅝-inch stud-bolts and nuts.

The mixture of water and condensed vapour falls to the bottom of the condenser, around the body of the air-pump, which is situated within the condenser, and is one casting with it. The condenser is divided into two compartments by a transverse diaphragm which surrounds the air-pump; in the larger of which, 2 feet 9 inches long, the condensation takes place.

The air-pump, figs. 475, is single-acting, 14 inches in diameter, with a stroke of 3 feet. It is of cast iron, ⅞ inch thick at the barrel, thickened to 1 inch at the ends, and 1¼ inches at the flanges. It is 4 feet 1 inch long over the flanges. It is lined with brass $5/_{16}$ inch thick, and is widened out
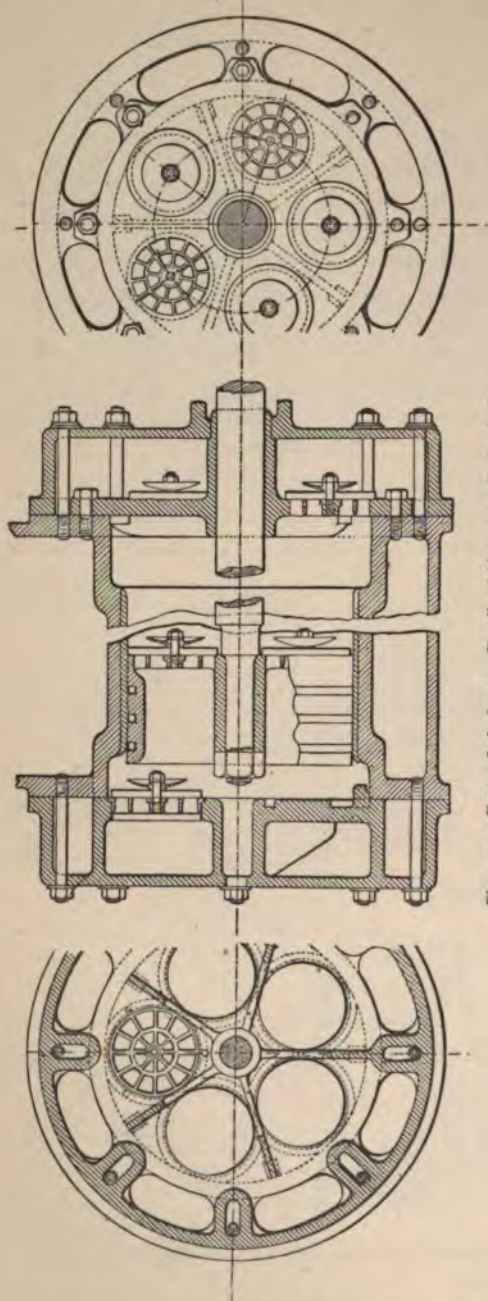
Figs. 475.—Easton & Anderson   Details of Air-pump.   Scale 1/24th.

at each end to a diameter of 16 inches, thus embracing a larger area of end surface for inflow and outflow. The water and vapour in the lower part of the condenser flow into a hollow cover on the end of the air-pump, from which it is drawn into the air-pump on the out-stroke, through five circular openings in the cover, fitted with india-rubber valves opening inwards. On the in-stroke the water passes through the bucket, which is fitted with four like valves opening towards the steam cylinder; and on the out-stroke it is expelled through a valve-fitted disc of five valves, on the delivery-end of the pump, into a hollow cover, whence it flows into the smaller compartment of the condenser. From this chamber the water flows off by a 9-inch overflow cast-iron pipe, alongside the injection-pipe. An opening is made in the top of this chamber, fitted with a short funnel, 3 inches in diameter, for the escape of air and vapour discharged by the pump. There are five disc-valves at each end of the barrels of india-rubber, 5½ inches in diameter and ½ inch thick, on grid seatings 5 inches in diameter of opening, fastened with a convex 3½-inch brass disc over each valve to limit the opening of the valve. The covers of the air-pump are of cast iron, 5½ inches wide; of which the front cover is single, and dished, the flat part being ⅝ inch thick, the rim ¾ inch, and the junction-flange 1 inch. The front valve-diaphragm is of brass, 1 inch thick, fixed to the end of the air-pump with eight ¾-inch stud-bolts and nuts. The nave is produced to enter the stuffing-box in the cover. The back cover is double and hollow, ⅝ inch thick at the outer face and ⅞ inch at the inner or valve face. The valve seats are let into openings through the inner face of the back cover, 5½ inches in diameter, the gridding of the seats being of ¼-inch thick bars. Each cover is bolted to the barrel with eight ¾-inch stud-bolts and nuts. The air-pump rod is of steel, reduced within the bucket, which is fastened to it by a nut at the end. It is extended through the stuffing-box at the back of the cylinder, and is fastened in a socket on the end of the piston-rod by a cotter inside the cylinder cover. By this disposition the air-pump rod works through both stuffing-boxes clear of a joining.

The base-plate or bed, shown in pages 99, 100, 108, and 109, is of cast iron, of a uniform depth of 15 inches. The sides are ⅞ inch thick, joined to a flat base 1 inch thick; 9 inches wide at the steam cylinder, and 6 inches wide at the condenser and the pedestal. The bed is for the most part open above, to make room for the steam cylinder and the condenser; the centre-line of which is 12 inches above the level of the bed. It presents a bearing, 6 inches wide, at each side for the base flanges of these members, which are 1½ inches and 1¼ inches thick respectively. The base-plate is open also between the guide bars, where it is 1¼ inches thick. It is continuous at the prolongation forming the main pedestal, about which also it is 1¼ inches thick. The bed is 3 feet 10 inches wide at the upper side, and 4 feet 8 inches at the base. But it is narrowed to 10 inches wide at the upper side for the pedestal, and to 1 foot 11 inches for the condenser. The bed is cast in two pieces, of which one, comprising the steam

cylinder and the pedestal, is 20 feet 5 inches long, and the other for the condenser is 6 feet 5 inches, making the total length 26 feet 10 inches. The two pieces are united by seven 1-inch bolts and nuts—three at the top, and two at each side. After the bolts were screwed up, three 1-inch holes were drilled into the joint from the outside, and a 1-inch pin, 1½ inches long, was driven into each hole—acting as jam-pins. The bed is planed on the top to receive the steam cylinders, guide bars, and condenser. It is bolted down to the foundation with nine holding-down bolts.

The steam cylinder is secured to the bed with twelve 1¼-inch bolts and nuts, six at each side. The condenser is secured with eight 1-inch bolts and nuts. The cylinder and condenser are each further secured by two joggles, one at each side, driven into slots cut half into the bed and half into the base flange. For the cylinder these are 2 inches wide and 1½ inches deep; for the condenser, 1½ inches by 1 inch.

The governor is of the Porter type, weighted, the E size, having 2½-inch balls. It is adjusted to rise when the engine is running at 80 revolutions per minute, when the piston makes a speed of 480 feet per minute. It is driven by a 2-inch band passed round the main shaft, which is 10½ inches in diameter, and over a 7-inch pulley, from which the governor is driven by mitre-gear, making $80 \times \dfrac{10\frac{1}{2}}{7} = 120$ turns per minute. It is connected to the throttle-valve, by which it controls the speed; but it is only required to act on the throttle-valve when the fans cease to draw water.

The feed-pump, figs. 476, is single-acting, 4½ inches in diameter, and has a short stroke of 6 inches, being driven direct from the expansion-
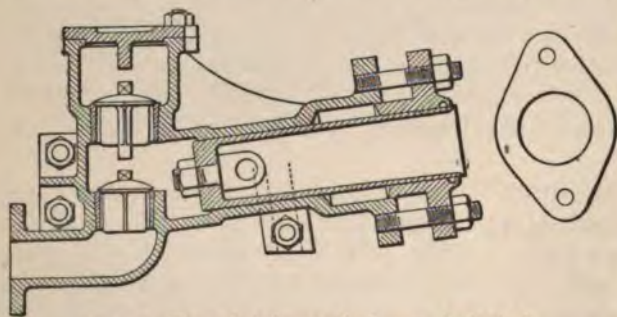
Figs. 476.—Easton & Anderson: Feed-pump. Scale 1/12th.

eccentric, by a connection from the lower side of the eccentric-strap. It is fastened to one side of the bed. The plunger is of brass, 4½ inches in diameter, and 16¼ inches in length. It is 5/16 inch thick, except the bottom, which is 1¼ inches thick, and takes the 1¼-inch iron eye-bolt by which it is driven, the bolt being passed through the bottom and fastened by a nut, 1¼ inches deep, outside. The eye-bolt is forked to receive the end of the rod by which it is driven. The hinge-pin is 1¼ inches in diameter, and 1¾ inches long between the forks. It is fastened to the eye-bolt by a ¼-inch countersunk screw, which is let in at the circumference parallel to the axis of the bolt. The other end of the rod is forked and is pinned by a 1¼-inch bolt to the lower corner of the eccentric-strap, having 2 inches length of bearing between the forks. The head of

the pin is sunk flush into the strap, and the pin is secured by a cotter through the other end. The plunger exactly fits the barrel of the pump, which is of cast iron, bored out, and is ⅝ inch thick. The suction-pipe and delivery-pipe are of wrought iron, 2½-inch bore. The suction-pipe draws the heated water from the condenser, and on the delivery-pipe a cast-iron air vessel is fixed, 8 inches in diameter outside, of ½-inch metal, and 18 inches high. There are two three-leaved disc-valves, 2½ inches deep, and 3 inches and 3½ inches in diameter respectively, for the suction and the delivery, the latter above the former at the base of the barrel— so placed as to incur a minimum of unoccupied space between the valves and the plunger when the latter is at the bottom of its stroke. The lifts of the valves are respectively ¾ inch and ⅝ inch; that of the suction-valve being checked by a central stem formed on the upper valve, and that of this valve being checked by a stud on the cover. The cover is fastened down by two ⅞-inch bolts and nuts. The valve-casing is of ½-inch metal.

The weight of one engine complete is 19 tons, including 6 tons, the weight of the fly-wheel. Each of the four engines, for average duty, lifts 2857 cubic feet of water per minute an average height of 20 feet, the maximum height being occasionally 40 feet. The centrifugal pumps have vertical spindles, and single-inlet fans 4 feet 10 inches in diameter, with inlets 2 feet 10 inches in diameter. Steam of 60 lbs. pressure for the four engines is supplied by six triple-flue boilers, 7½ feet in diameter and 25 feet 9½ inches long, having three 2½-feet through-furnace tubes each. Of these, five are in steam for four engines, and one is spare. The total grate-area for each boiler is 45 square feet. Each boiler is capable of evaporating 70 cubic feet of water per hour.

CHAPTER IX.—HORIZONTAL CONDENSING STEAM ENGINE
OF 20 NOMINAL HORSE-POWER.

CONSTRUCTED BY MESSRS. MARSHALL, SONS & CO., GAINSBOROUGH.

(Cylinder 14½ inches in diameter, stroke 30 inches.)

A general elevation and plan of this engine are shown in figs. 477. The frame-bed is of the bayonet form, having the main plummer-block and the guides cast in one with the bed. It is hollow, and is planed at the lower surface. The cylinder is bolted endwise to the target end of the bed, and is overhung. The condenser is placed behind the cylinder on a separate base, and is connected to it by a distance-piece, to ensure accurate relative adjustment. The air-pump, within the condenser, is worked direct from the piston-rod of the engine.

The cylinder, figs. 478, is 14½ inches in diameter, with a stroke of 30 inches. It is steam-jacketed on the barrel, clothed with hair-felt, and lagged with teak-wood. The cylinder is of cold-blast iron, the jacket

being $^{13}/_{16}$ inch thick, and the liner or barrel $\frac{7}{8}$ inch thick, forced into the jacket.
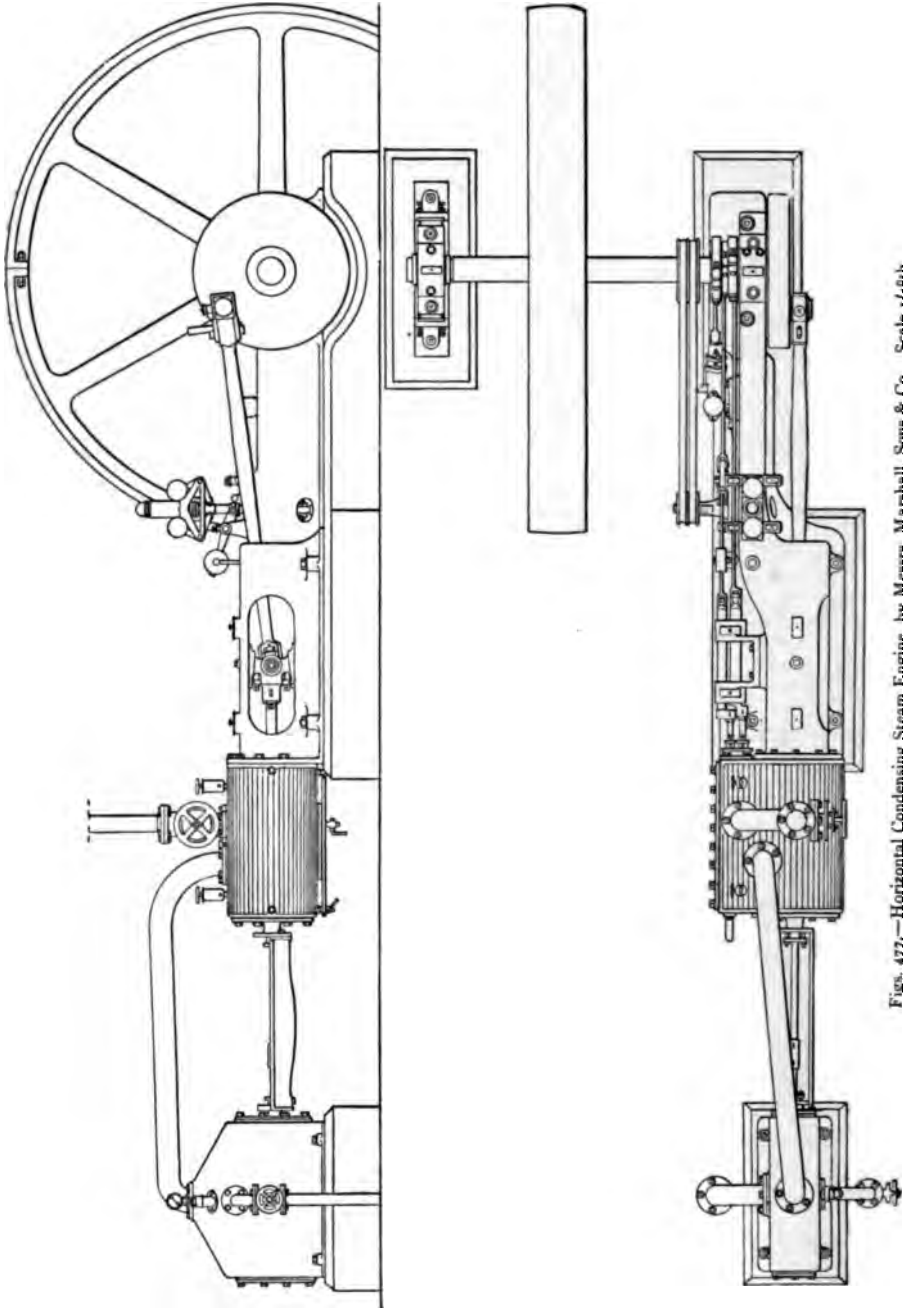
Figs. 477.—Horizontal Condensing Steam Engine, by Messrs. Marshall, Sons & Co.   Scale 1/46th.

The form of the frame is shown in the cross sections, figs. 480. It is of $\frac{3}{4}$-inch metal, thickened to $\frac{7}{8}$ inch at top and bottom to form the

guides for the crosshead, bored out to a diameter of 12½ inches.   The
brasses of the main bearings are in four pieces, as shown in the detail,
fig. 479, capable of adjustment horizontally.   The square tabs on the
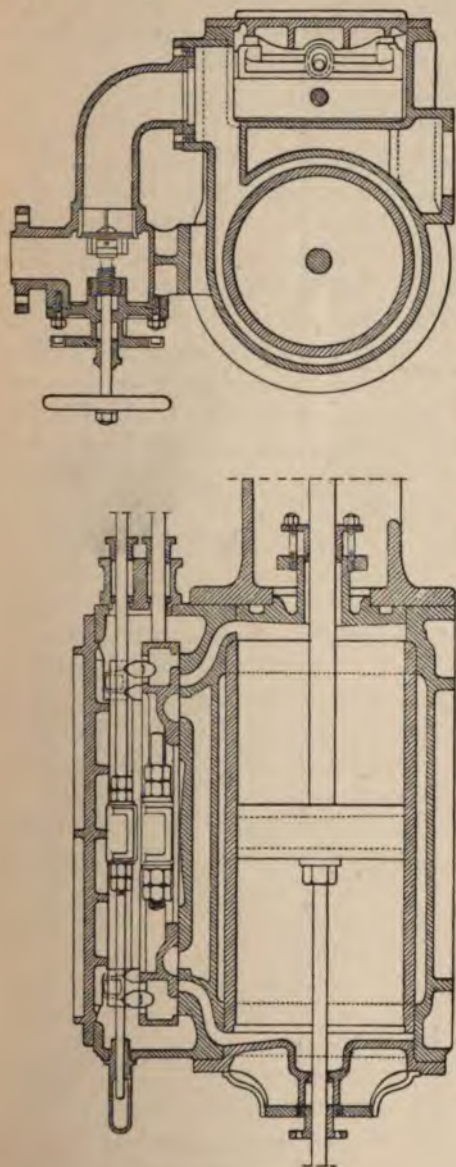
Figs. 478.—Marshall's Horizontal Engine: Sections of Cylinder.   Scale 1/16th.
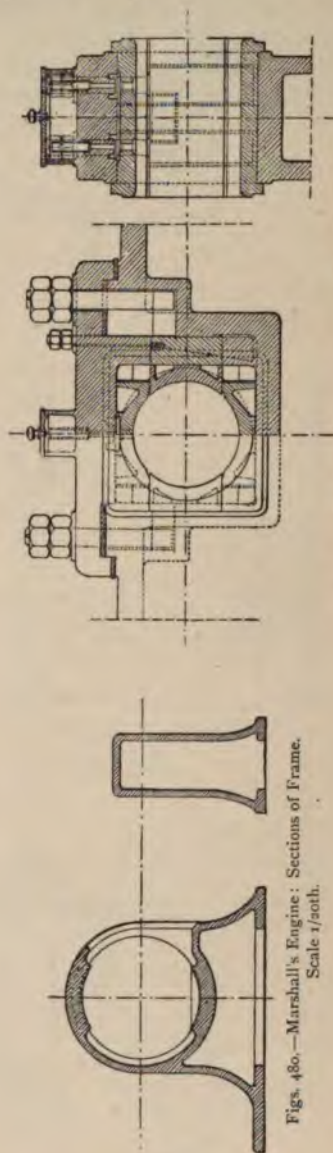
Fig. 479.—Marshall's Horizontal Engine: Main Bearing.   Scale 1/10th.
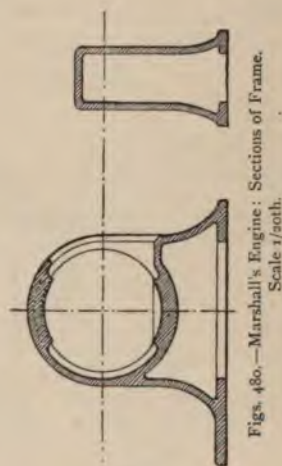
Figs. 480.—Marshall's Engine: Sections of Frame.   Scale 1/20th.

side brasses prevent their being forced up too tightly to the shaft, by the
two adjusting wedges at one side.   As the brasses wear away the tabs are
eased down.

The valve-chest, fig. 478, is of ⅝-inch metal.   The slide-valves are
double-ported, and have short steam passages, with a separate exhaust
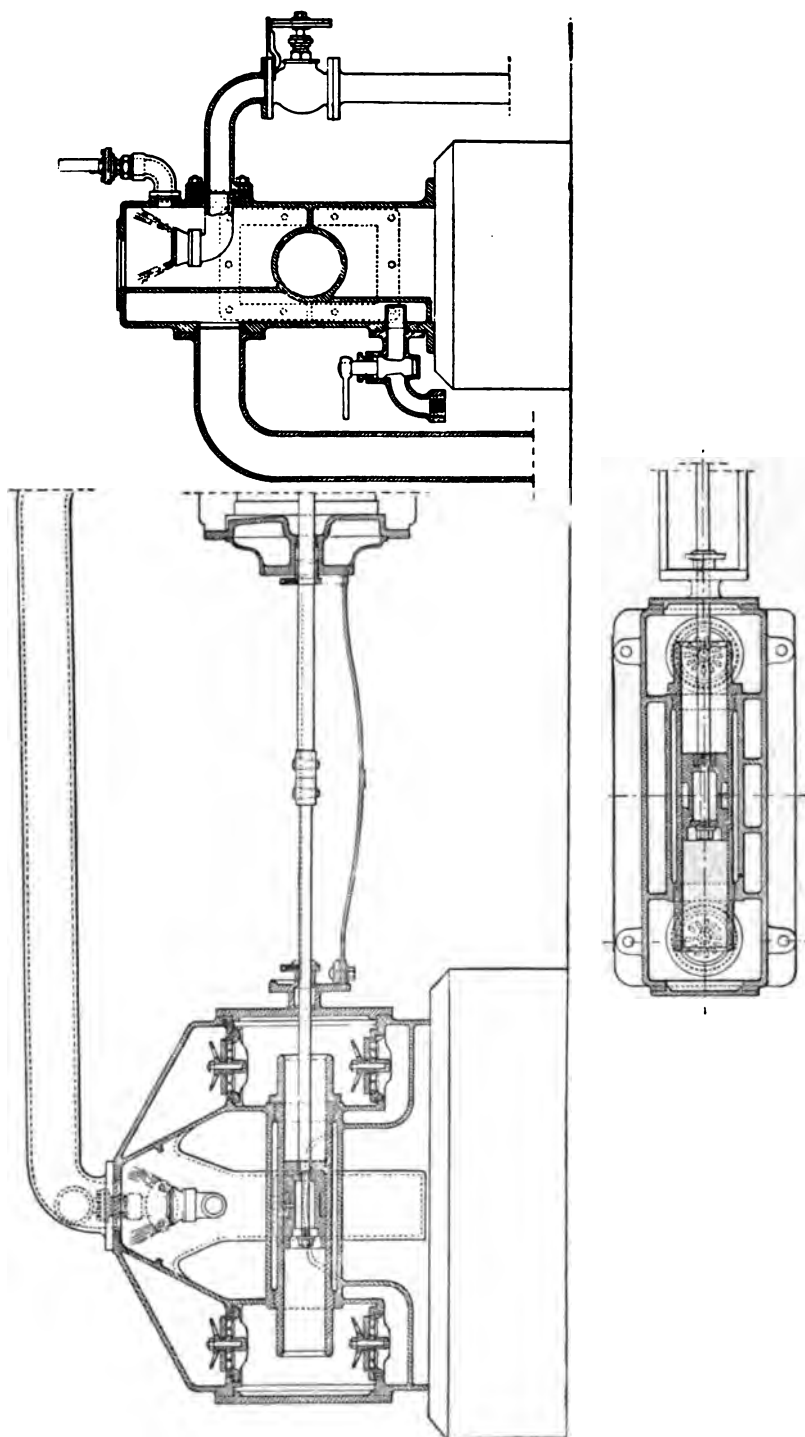
Fig. 481.—Marshall's Horizontal Steam Engine: Sections of Condenser and Air pump.   Scale 1/20th.

port at each end of the cylinder. The expansion-valve works on the back of the main valve. They are driven by separate eccentrics, and the spindles are guided compactly in bearings bolted to the back of the frame bed. The travel of the expansion-valve is varied by the governor, so as to cut off the steam within the limits of 0 per cent and 58 per cent of the stroke. The steam-pipe is of 3-inch wrought-iron pipe ¼ inch thick. The exhaust-pipe to the condenser is 5 inches in diameter, of cast iron ½ inch thick.

The condenser, figs. 481, is mostly of ½-inch metal. It is fitted with india-rubber disc-valves, and a double-acting air-pump, 4½ inches in diameter, coupled to and worked direct by the piston-rod. It is fitted with four india-rubber valves—two inlet and two outlet, as shown.

The piston, figs. 482, is 4⅝ inches thick, and is fitted with the Mather packing—two L-shape cast-iron rings, sprung out by a steel coil to com-pensate for wear. The width of the two packing rings together is 2⅞ inches. The piston is in two pieces—a body and a junk-ring, held together by six ¾-inch brass screws, of which the heads are let in flush with the surface of the junk-ring, and are notched to receive the driver for screwing them in. The piston-rod is of steel, 2⅜ inches in diameter. It

Figs. 482.—Marshall: Piston. Scale 1/10th.

is let into the piston with a taper end, 2⅝ inches and 2 inches in diameter, tapering ⅝ inch in 2½ inches, or at the rate of 1 in 4. The rod is fastened with a 2-inch nut, 2 inches thick, secured by a through-pin.

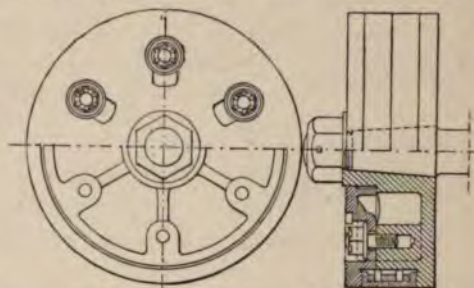The crosshead, figs. 483, is of malleable cast iron, forked to take the connecting-rod. The gudgeon is of steel, 2¾ inches in diameter, and 3¾ inches long between the sides of the crosshead, which are each 1½ inches thick to give bear-ing for the pin. The pin is let in with a taper head, 3 inches and 3³/₃₂ inches in diameter, tapering 3/₃₂ inch, or at the rate of 1 in 15. The gudgeon is fastened with a washer and a nut, ⅝ inch thick; and the head is prevented from turn-ing by a short key, ⅜ inch

Figs. 483.—Marshall: Crosshead. Scale 1/10th.

square, driven in from the outer side. The crosshead is let on the end of the piston-rod for a length of 4½ inches, tapering from 2⅜ inches to 1⅞ inches, or ½ inch in 4½ inches, at the rate of 1 in 9. It is fastened with a cotter 2 inches by ½ inch thick, and a nut ¾ inch thick, against the end of the socket. The slides are of wrought iron, with large wearing

surfaces, 6 inches wide, 11 inches long, and turned to a radius of 6¼ inches to fit the guides. They fit on and are notched into the upper and lower faces of the crosshead, which are wedge-form, so that by longitudinal adjustment the slides may be adapted to the exact radius of the guides, and so compensate for wear. The adjustment is effected longitudinally by bolts and double-nuts, which engage in eyes cast on the crosshead and the slides.

The connecting-rod, figs. 484, is of steel. It is 7½ feet long, or six times the length of the crank. The bearing is 2¾ inches in diameter and 3¾ inches long at the crosshead end, and at the crank end it is 3½ inches in diameter by 5 inches. The smaller end is solid forged, and finished with an opening 3¼ inches wide, 6¼ inches long, to receive the brasses and the adjusting screw. The larger end is fitted with a butt, strap, gib and cotter. The body of the rod is 2⅜
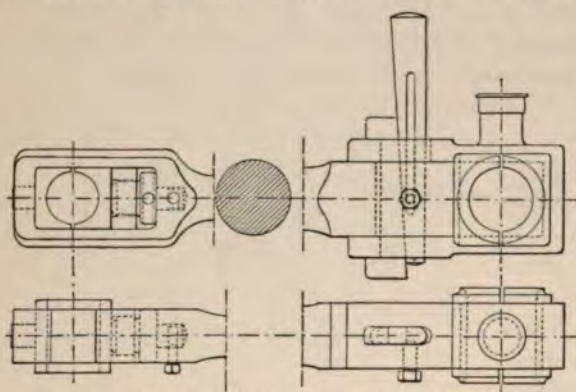
Figs. 484.—Marshall: Connecting-rod. Scale 1/10th.

inches and 3¼ inches in diameter at the ends, and is enlarged to 4 inches at the middle.

The main shaft is of steel, 6½ inches in diameter, and 8 feet in length. The crank-pin is of steel, having a journal 3½ inches in diameter, 5 inches long. It is forced by hydraulic pressure into a cast-iron disc, 3 feet 3 inches in diameter. The disc is counterweighted to balance the crank-pin and the proportion of the connecting-rod supported by the crank-pin. It is forced on the shaft by hydraulic pressure, and keyed. The fly-wheel is 11 feet in diameter, and 14 inches wide at the rim. It is cast in halves for convenience of transport, which are bolted together. It is fastened on the shaft with one key.

The governor is of the Hartnell type, already explained, page 73, detailed in figs. 485. The normal speed is 242 turns per minute. The speed of the engine is regulated automatically by the action of the governor on the expansion-valve, through the vibrating link. The balls are 5 inches in diameter, on arms 6¼ inches long between centres. The horizontal arms of the bell-cranks are 4⅞ inches long. The governor is driven by two belts from the main shaft, for security in case of one belt failing.

The condenser, placed behind the cylinder, is of 9/16-inch metal. It contains the air-pump, the barrel of which is of ⅞-inch metal. The pump is double-acting, and is worked directly off the end of the piston-rod; the pump-rod being connected to the piston-rod by a sleeve or thimble and two cotters. The air-pump has a liner 4⅜ inches in diameter, in which a

solid piston works, packed with wood, and having the stroke of the engine, 30 inches. The valve-seats are of brass, with india-rubber disc-valves,
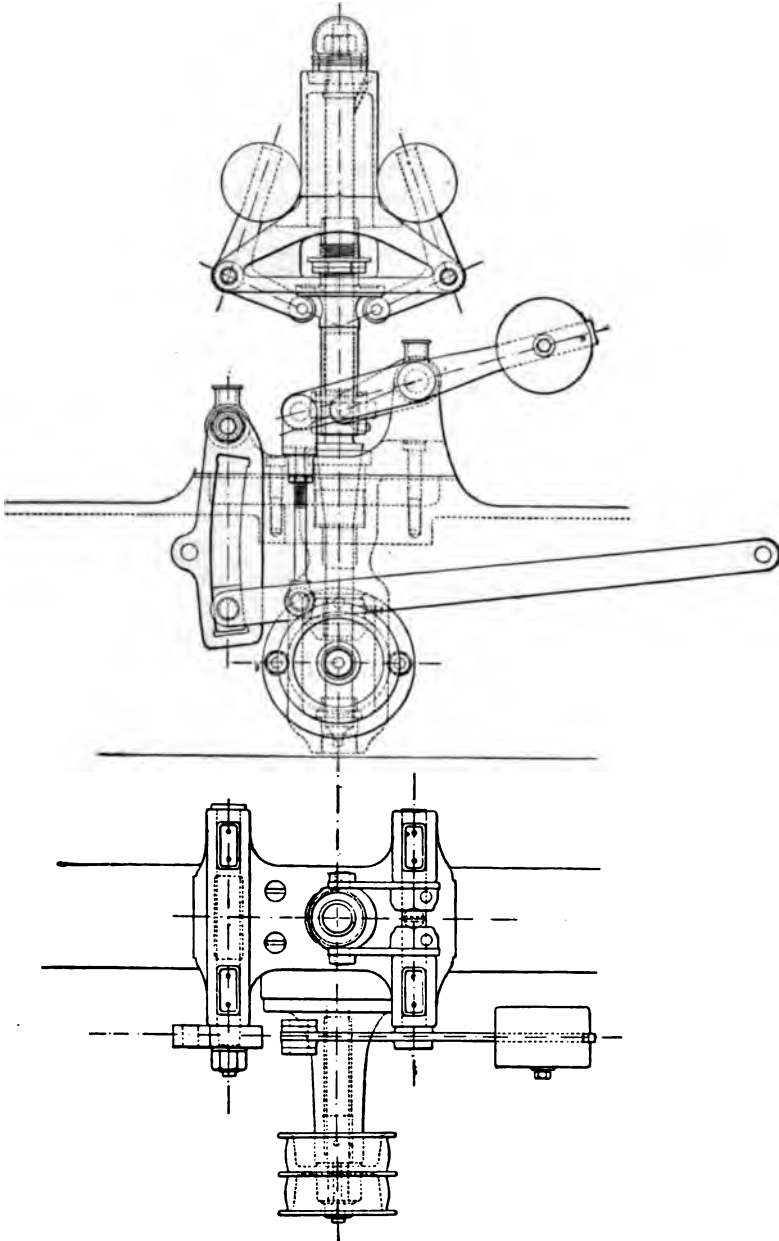
Fig. 485.—Marshall : Hartnell Governor.   Scale 1/12th.

5¾ inches in diameter, ⅝ inch thick. The injection-pipe is 2¼ inches in diameter. The exhaust-pipe into the condenser is 4¾ inches in diameter, of ½-inch metal. So also is the overflow pipe. The distance-piece con-

necting the condenser to the back cylinder-cover is trough-shaped, and it collects the oil and the water that drop from the glands, which can be withdrawn at intervals.

The feed-pump is single-acting, and is worked by a special eccentric on the main shaft. The plunger is 3 inches in diameter, and has a stroke of 3⅛ inches. The body of the pump and the valve-boxes are cast together, and are fitted with brass suction and delivery valves, having spiral wings or fins. A large air-vessel is connected just above the delivery valve. The suction pipe has 1¾ inches bore, and the delivery pipe 1½ inches.

The working pressure in the boiler is 80 lbs. per square inch. The normal speed is 70 turns, or 350 feet of piston, per minute. The cut-off can be varied from 0 to five-eighths of the stroke. Cutting off at 25 per cent, the engine indicates 60 horse-power.

The unit of nominal horse-power is measured by 10 circular inches of area of piston.

From 26 to 28 pounds of water as steam is consumed per indicator horse-power per hour.

The total weight of the engine is 174½ cwts., or 8 tons 14½ cwts., as follows:—

	Cwts.		Tons.	Cwts.
Frame, including main bearing	28½	or	1	8½
Cylinder, pipes, &c.	76½	or	3	16½
Net weight of engine	105	or	5	5
Fly-wheel	56½	or	2	16½
Condenser and air-pump	13	or	0	13
	174½	or	8	14½

The price of the engine with condenser is £302
    Do.   force-pump, when required................. 13
                                                    ——— £315

The price, £302, is at the rate of £34, 10s. per ton of weight.

CHAPTER X.
PAIR OF HORIZONTAL CONDENSING STEAM ENGINES.

CONSTRUCTED BY MESSRS. JAMES SIMPSON & CO., LONDON.

PLATE V.

(Cylinders 28 inches diameter, 42 inches stroke.)

A pair of horizontal condensing steam engines, having single cylinders, Plate V., were constructed for the Gun Factory, Royal Arsenal, Woolwich, and erected in 1884. They were specially designed to run at a high speed, and transmit the power direct to the first motion shaft, without the intervention of gearing. The cylinders are connected by straight and direct

Fig. 1.—LONGITUDINAL ELEVATIO

CONDENSER AND AIR-PUMP.　　　　STEAM-CYLINDERS.

PLATE V.
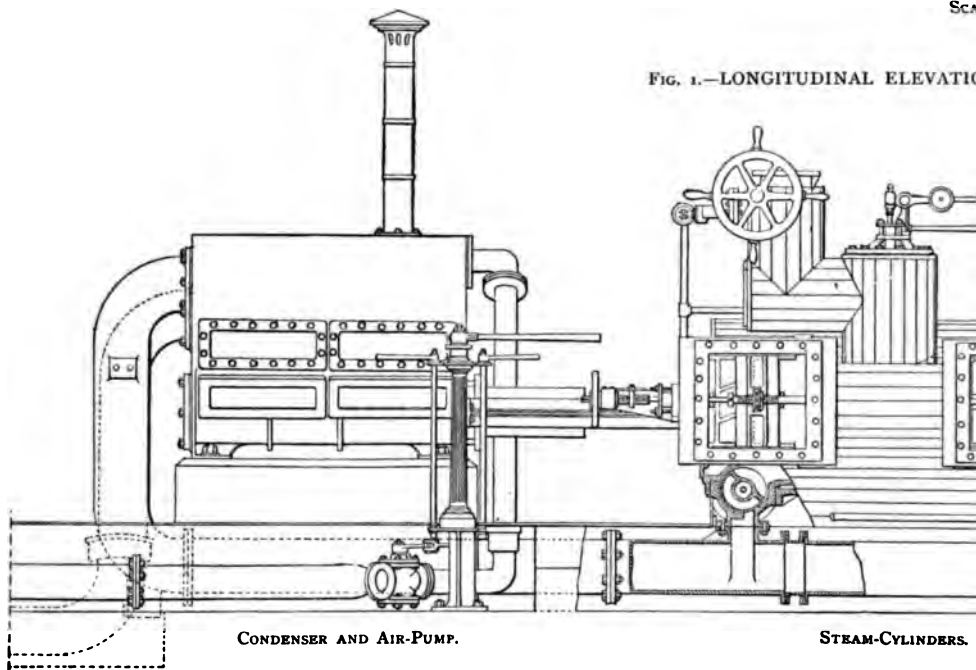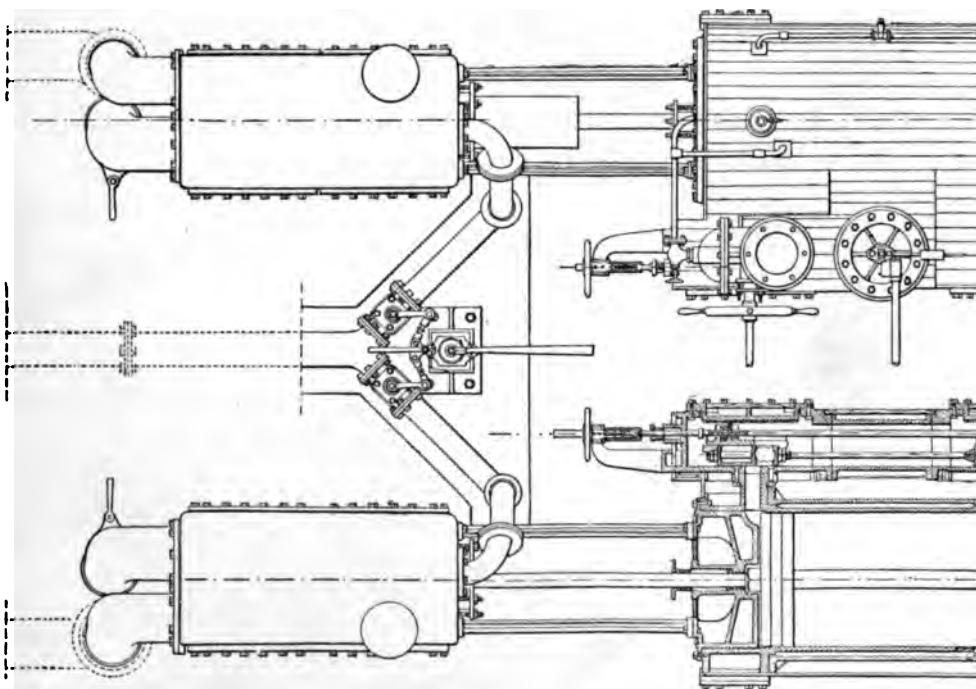
NSING STEAM ENGINES,

MPSON AND CO., LONDON.

CH = 1 FOOT
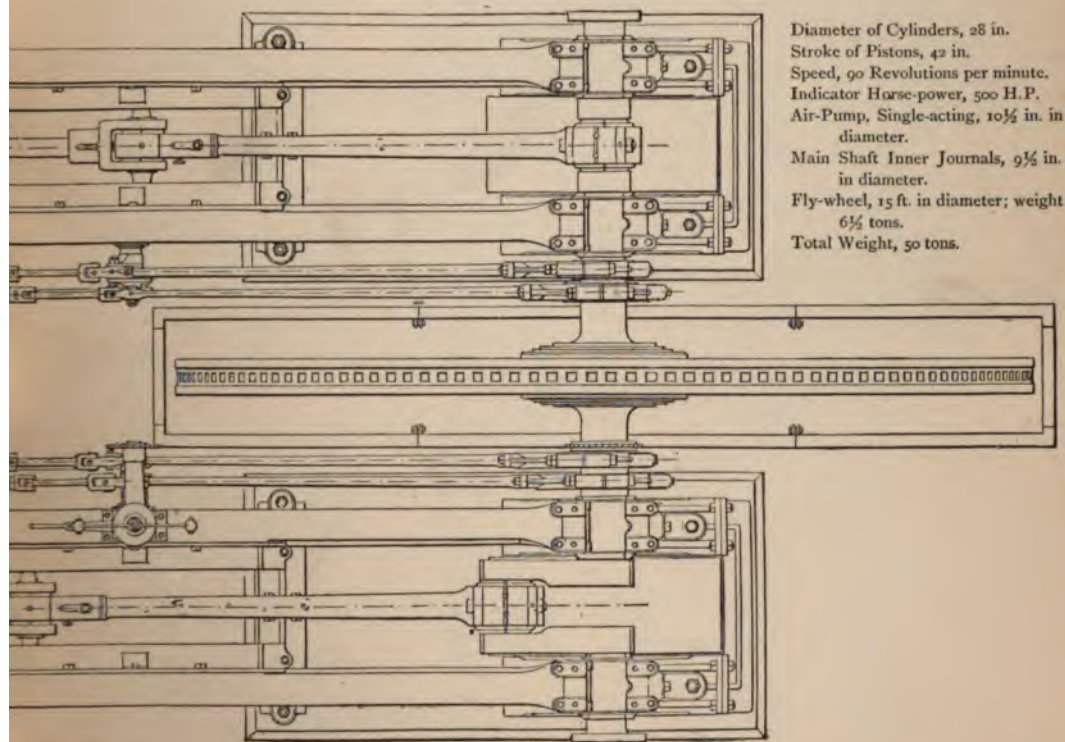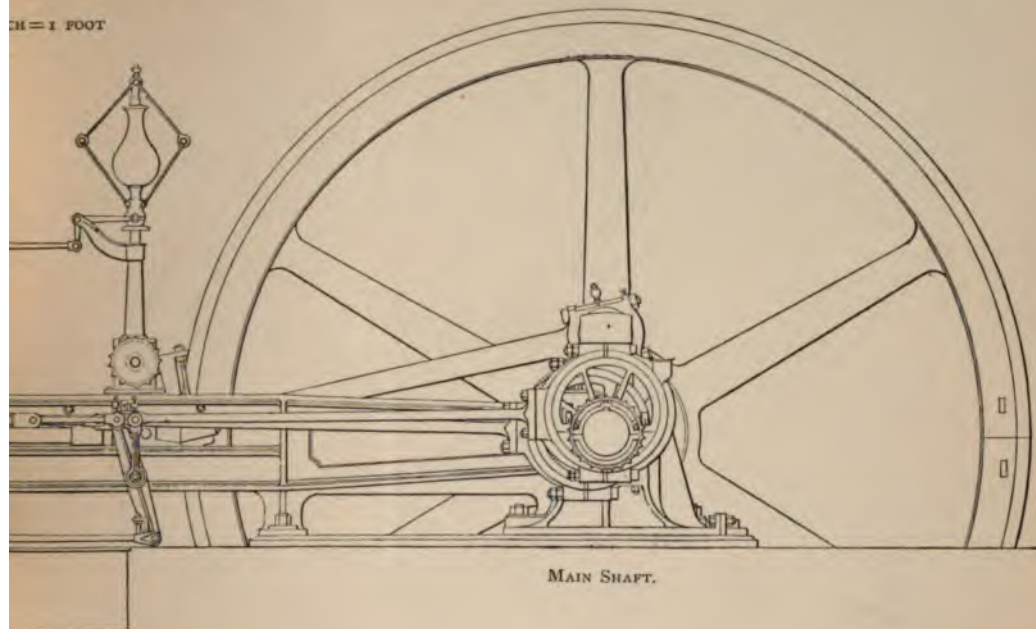
MAIN SHAFT.

Diameter of Cylinders, 28 in.
Stroke of Pistons, 42 in.
Speed, 90 Revolutions per minute.
Indicator Horse-power, 500 H.P.
Air-Pump, Single-acting, 10½ in. in
    diameter.
Main Shaft Inner Journals, 9½ in.
    in diameter.
Fly-wheel, 15 ft. in diameter; weight
    6½ tons.
Total Weight, 50 tons.

ning to one main
t, with double-limb
ks at right angles,
ning in four bear-
; with a fly-wheel
the middle of the
t. The valves are
gned to work al-
t in balance, with
sufficient pressure
hem to keep them
e faces. There is
ondenser for each
ne, placed behind
cylinder, with an
pump, on the same
re-line, worked by
extension of the
on-rod through the
t of the cylinder.
several parts of
engine—cylinders,
estal, and conden-
-rest on and are
ed down to the
dation by feet,
kets, or soles. The
ng pressure in the
is 60 lbs. per
inch; and the
speed is 90
or 630 feet of
per minute. The
engines are de-
to indicate 500
wer.

two engines
at a distance
apart between
re-lines. The
fig. 486, are
in diameter,
oke of 3½
y are thor-
m-jacketed.

Fig. 486.—Simpson & Co.: Steam Cylinder. Scale 1/20th.

ports of each cylinder are 3 inches by 18 inches in section; they

are short and direct, and open into a long steam chamber, in which there
is a main slide-valve to each port, with a cut-off slide-valve on the back of
each main valve. The ex-
haust-ports are 2½ inches
by 28 inches, one at each
end of the cylinder. At the
bottom the valves are circu-
lar, and, like Corliss valves,
reciprocate in cylindrical
seats. The valves are light
and handy, and can be
readily disconnected and re-
moved singly.

The cylinder is made up
of four separate castings,
bored, turned, and faced, and
bolted together. The barrel
or cylinder is one casting
with the back steam-passage,
and receives the back cylin-
der-cover. The front cylin-
der-cover is one casting with
the front steam-passage, and
the jacket is a separate cast-
ing, bolted to and between
the front cylinder-cover and
a flange on the barrel, at
the back. The covers are
of great depth, about 13½
inches, and they contain the
stuffing-boxes, the outer
ends of which are flush with
the outer faces of the covers.
The total length over the
cylinder-covers is about 6
feet 5 inches. The steam-
chamber is in three pieces,
faced and bolted together,
making a length of about
6 feet 9 inches inside; of
which the outer pieces are
the valve-chambers, and
the central piece connect-
ing these is cylindrical, 9 inches in diameter.

The direct clearance space at each end of the cylinder is 5/16 inch wide.
The total clearance, including the steam and the exhaust ports or passages,
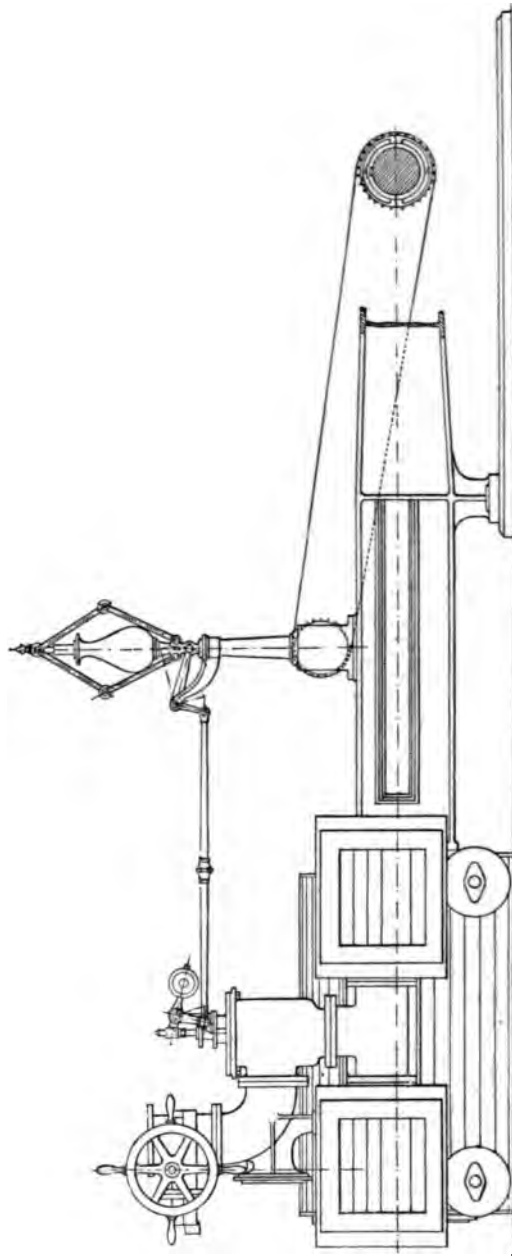
Fig. 487.—Simpson & Co.: General Arrangement of Steam-valve and Throttle-valve. Elevation. Scale 1/40th.

at each end, is 6.30 per cent of the working capacity of the cylinder.   The metal of the cylinder, the jacket, and the valve-chest is 1 inch thick.

Figs. 488.—Simpson & Co.: General Arrangement of Steam-valve and Throttle-valve.   Plan.   Scale 1/40th.

The steam-valve faces of the cylinder are very short, each of them being limited to the length of the steam-port plus the thickness of metal at each edge of the port. The length of the face is, in fact $(3 + 1 + 1 =)$ 5 inches. The main valve is $12\frac{1}{2}$ inches long, and, therefore, it to a great extent overhangs the valve-face. It is of an open-box form, and whether it be covered and closed by the cut-off slide, or uncovered, the steam-pressure on each of these valves is to a great extent balanced, seeing that the steam has access to the lower faces of both valves, for the most part.

The main valves are connected to each other by a rod, adjustable in length, with double-nuts at each end. The arms of the exhaust-valves are connected by a rod, and so move in unison. The main steam-valves and the exhaust-valves are moved by one eccentric on the main shaft, 22 inches in diameter and 3 inches wide. An intermediate lever is reciprocated by the eccentric, and by links from the upper and lower ends of it the main valves and exhaust-valves respectively derive their motion. The cut-off or expansion-valves are moved by a separate eccentric. The valves are adjustable for various degrees of expansion, cutting off at from 10 per cent to 70 per cent of the stroke, by means of a screw and hand-wheel at the back end of the valve-chest. The screw is hollow, formed square to receive the end of the valve-rod, which is squared. By turning the screw the valve-rod also is turned, and by the right and

left hand screws on it the valves are correspondingly shifted. A graduated scale is attached to each hand-wheel and screw, from which the point of cut-off can be read off. The eccentric-rods are of wrought iron, and the valve-spindles and pins of mild steel.

The steam-valve, and the throttle-valve with its connection to the governor, are shown in general arrangement in figs. 487, 488, and 489.

The piston of each cylinder is 7 inches deep; fitted with Mather and Platt's packing rings—two L-shape rings with a spring-steel coil behind them, as explained elsewhere. The piston-rod is of mild steel, 4 inches in diameter. The extension of the rod to the air-pump is 3 inches in diameter.

The connecting-rod, figs. 490, is of wrought iron, 8 feet 3 inches long, or
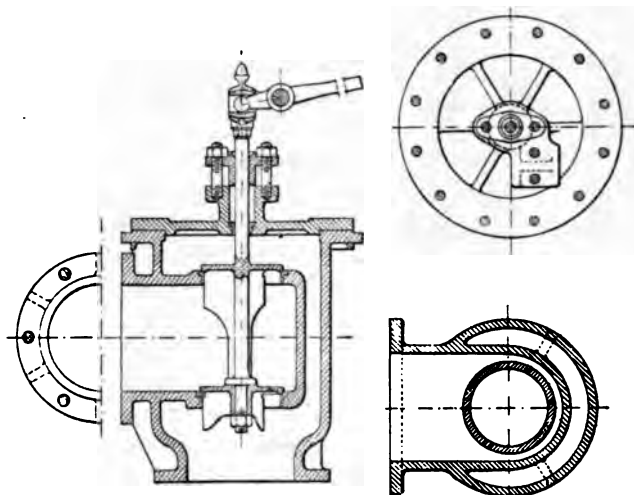
Figs. 489.—Simpson & Co.: Throttle-valve.   Sectional Views.   Scale 1/16th.
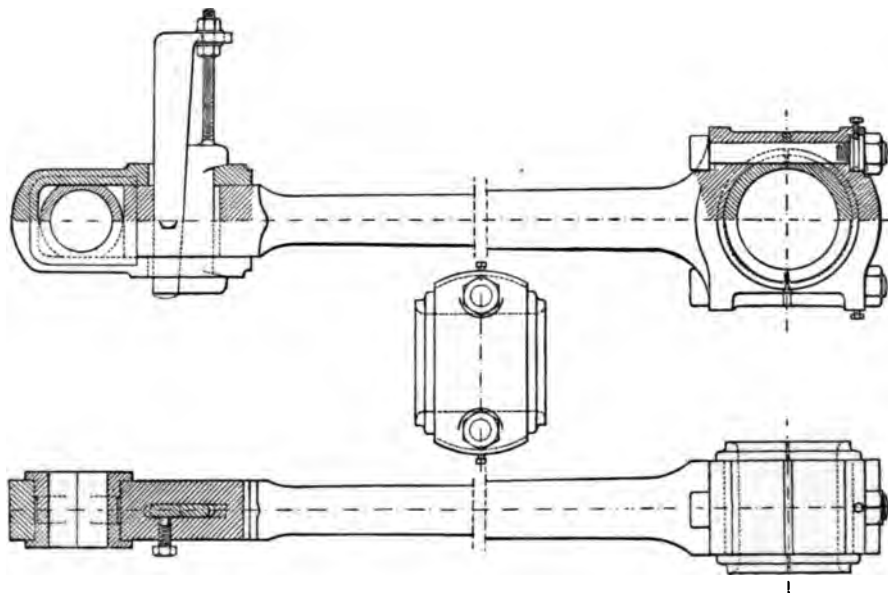
Figs. 490.—Simpson & Co.: Connecting-rod.   Scale 1/16th.

4.71 times the length of the crank. It is formed with a uniform taper in diameter from one end to the other. The main shaft is of wrought iron,

solid forged, in two portions coupled together, with flanges at the centre. In each portion there is one sweep-crank—a crank having two webs or limbs —and the two portions are bolted together, with the cranks at right angles to each other.   There are two shaft-bearings for each cylinder; the inner journals are 9½ inches in diameter, and the outer journals are 8½ inches in diameter; and 13 inches long.   The crank-pins are 8½ inches in diameter, 11 inches long.   The diameter of the central coupling is 21 inches, and it is the seat of the fly-wheel, which is bored to fit it.   The limbs of the cranks are 6 inches wide by 11 inches in section; but they are reduced or excavated at the inner sides at the crank-pin to 4½ inches in width, making the length of the crank-pin 3 inches more than the width apart of the limbs, or 11 inches of length.   The shaft is made with a solid flange-coupling at each end for direct connection to first-motion shafts. All the bearings are made of phosphor-bronze.   Those of the main shaft are made each of four distinct parts; and each part is fitted with fixtures and means of adjust-ment, so that all wear
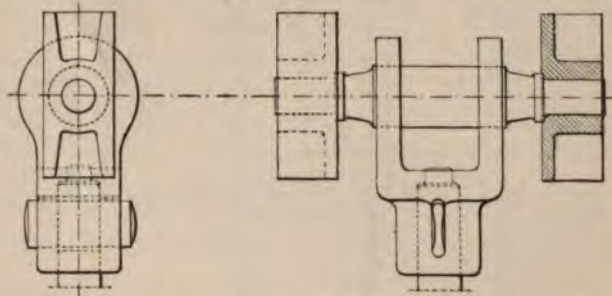
Figs. 491.—Simpson & Co.: Crosshead and Guide Blocks. Scale 1/16th.

in every direction may be taken up, even while the engine is working. The fly-wheel is 15 feet in diameter and 7½ inches wide at the rim, by 10½ inches (see figs. 492), and it weighs 6½ tons.   It is cast in halves, which are cottered together.   It is fastened on the shaft with three steel keys.

The crosshead guides, fig. 491, can be conveniently removed, and they are easily accessible for examination.

The frame for each engine, figs. 492, consists of two cast-iron girders, 21 inches deep, each of them one piece with the corresponding pedestal; bolted to the cylinder-cover, one at each side, and connected at the far ends, beyond the crank, by a cross-tie of cast iron.   The webs of the girders are of 1-inch metal; the upper flanges are 1⅛ inches thick, and the lower flanges 1⅜ inches.

The condenser, fig. 493, is of cast iron, 4 feet 10 inches long, 2 feet 3 inches wide, and 4 feet high, and is of ⅞-inch metal.   The exhaust steam is con-ducted from the cylinder by a 10-inch cast-iron pipe, below the floor, under the condenser to the back, where it is discharged into the upper part of the condenser, and meets and is condensed by cold water delivered there from a cast-iron pipe at the front.   Within the condenser the water falls through a horizontal continuation of the pipe, of which the upper half is of sheet iron, and the lower half of copper, and perforated.   The con-densed steam and water fall through a number of small india-rubber valves opening downwards into the air-pump, which is at the bottom of the

condenser, and is forced up through valves opening upwards, into a chamber, from which it flows off by a 9-inch overflow pipe. This delivery chamber is supplemented with an upright pipe, 5 inches in diameter,

Figs. 492.—Simpson & Co.: Frame and Pedestals.
Scale 1/40th; details 1/20th.
Fly-wheel: scale 1/16th.

Rim of Fly-wheel: Section.
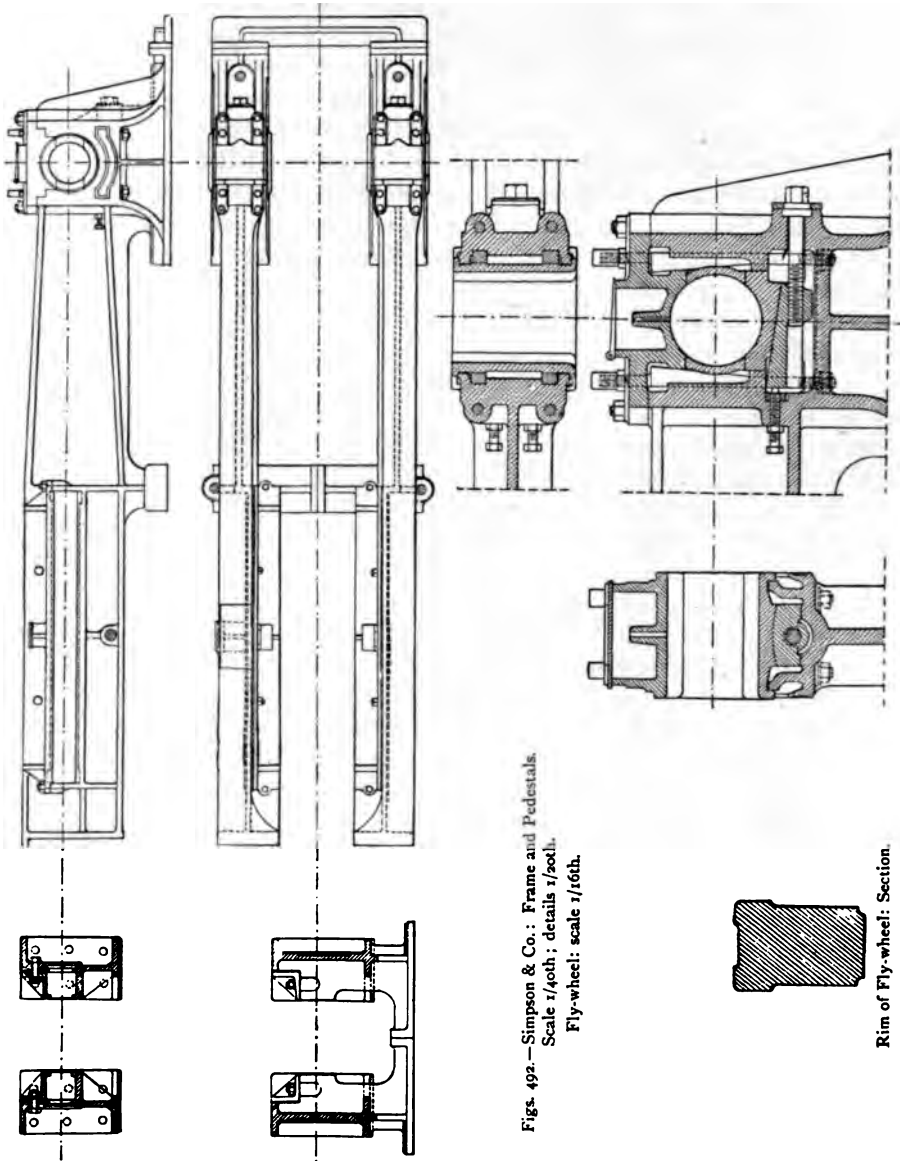
standing 3 feet 9 inches above the condenser, for the separation and escape of air from the discharged water. The 10-inch exhaust-pipe is 16 feet in length, in a direct line under the floor, and a section of it, 4 inches long, is of thin copper, to provide for expansion and contraction. The water supply for the condenser is brought in a 6-inch pipe, branched into two

4-inch pipes, one to each condenser. The branch pipes are fitted with separate stop-cocks at the parting, connected to a hand-lever, by which the supply is regulated. The air-pump is single-acting, 10½ inches in diameter. The condenser is connected to the cylinder by two cast-iron ties, one at each side. The boilers are fed by means of a donkey-pump.

The factor of safety is 9.

The governor is a high-speed weighted governor, driven by means of a pitch-chain from the main shaft, over 15-inch and 10-inch pulleys; so multiplying the speed of revolution to 135 turns per minute. The governor controls two double-beat balanced steam throttle-valves, one of which is situated on the valve-chest of each engine. See figs. 487 and 489, page 122.

The weight of the pair of engines is as follows:—

	Tons.
Framing and main pedestals	7
Fly-wheel	6½
Cylinders, &c., including all pipes inside the engine-room	18
Crank shaft, fly-wheel race, connecting-rods, air-pumps, condensers, &c.	18½
Total	50
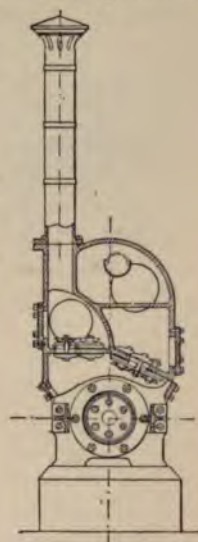
Fig. 493.—Simpson & Co.: Condenser and Air-pump.   Cross Section. Scale 1/40th.

The foundations are of brickwork in cement. The cylinders, frames, and condensers are bedded on large stones.

Chapter XI.—HORIZONTAL NON-CONDENSING RIDER ENGINE, of 8 HORSE-POWER.

CONSTRUCTED BY MESSRS. HAYWARD TYLER & CO., LONDON.

(Cylinder 9 inches diameter, 18 inches stroke.)

The Rider engine, figs. 494, is so designated for its valve-gear, which has an expansion valve of the Rider class, already noticed, page 38, in addition to the main valve. It is constructed with a hollow bed-frame resting for its whole length and width on the foundation, and an overhung steam-cylinder.

The engine here illustrated is one of 8 nominal horse-power, having a 9-inch cylinder, with a stroke of 18 inches, making 100 turns, or 300 feet of piston, per minute. The unit of nominal horse-power is an allowance of 10 circular inches of piston area. The working pressure in the boiler is 60 lbs. per square inch.

The bed-frame, figs. 495 and 496, is of hollow tube-girder form, 6 feet 7 inches in length by 19 inches wide at the base. The bearing for the main shaft, the guide-bars, and the front cover of the cylinder, are cast in one
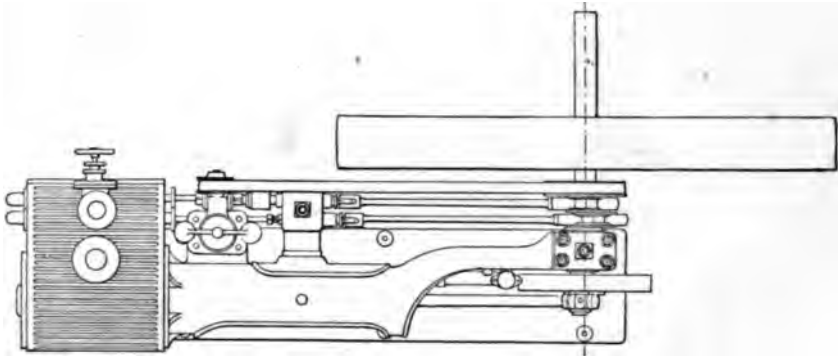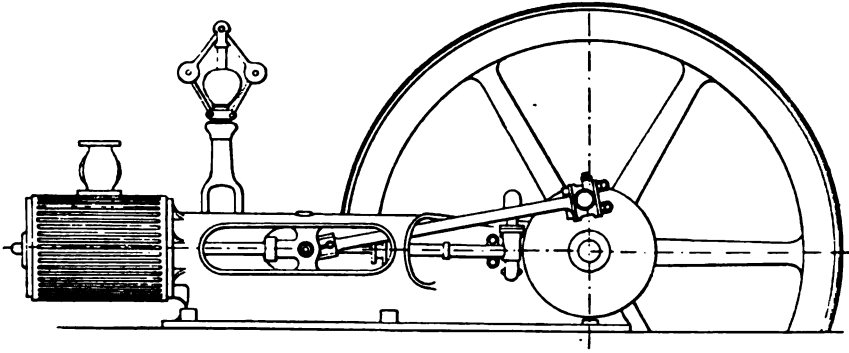
Figs. 494.—Hayward Tyler & Co.: Horizontal Non-condensing Rider Engine.   Scale 1/32d.
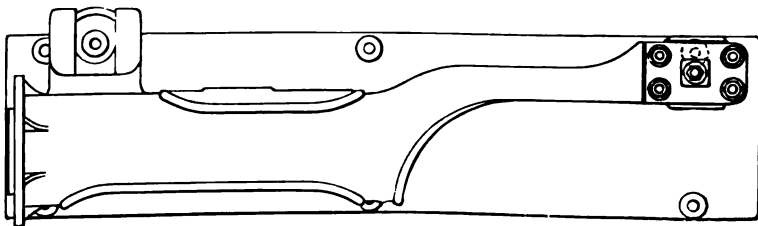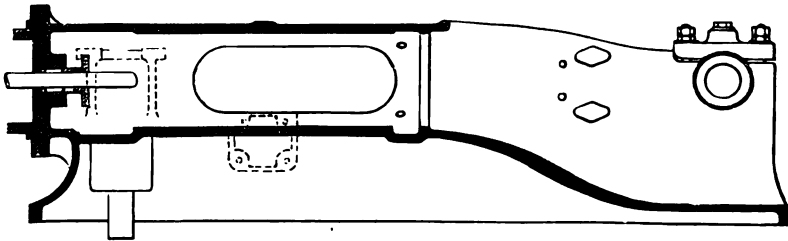
Figs. 495.—Rider Engine. Bed-frame. Scale 1/20th.

with the bed—forming a direct connection between the cylinder and the main shaft. It is completely cylindrical at two places—the cylinder-cover
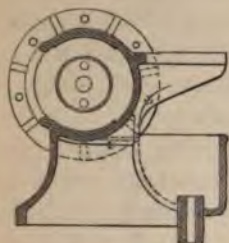
Fig. 496.—Rider Engine: Bed-frame.
Cross Section. Scale 1/20th.

and the ends of the guides; and it is open at the front and the back intermediately. The guides are bored out to a radius of 5 inches; they are 6½ inches wide. The metal is 9/16 inch thick, except at
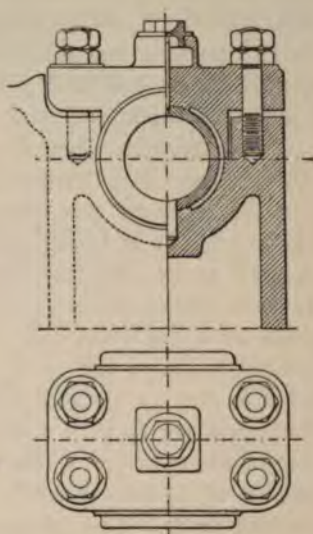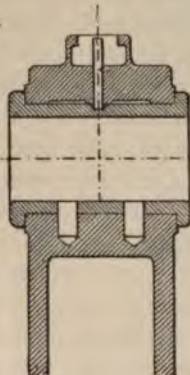
Figs. 497.—Rider Engine: Main Bearing. Scale 1/8th.

the guides, where it is augmented to ⅞ inch. In the flanks, or stool portion, it is ⅝ inch thick, and at the base it is 1 inch. The centre-line of the
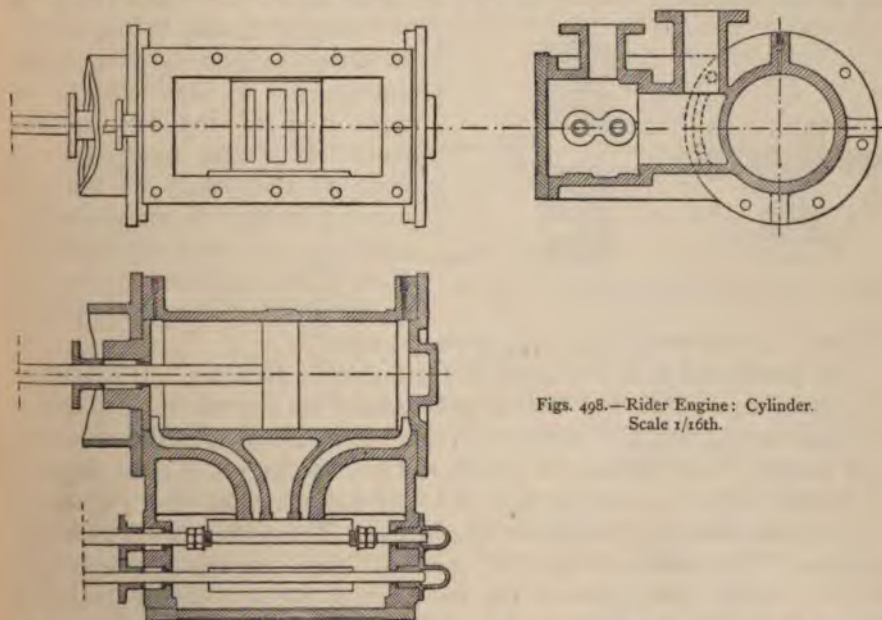
Figs. 498.—Rider Engine: Cylinder.
Scale 1/16th.

cylinder is 13½ inches above the base-line, and it is 4¾ inches horizontally from the side of the main bearing. The frame is joined to the cylinder

with a flange 1 inch thick, and seven ¾-inch bolts and nuts at 6 inches apart, forming in fact the front cover of the cylinder. The central portion holding the stuffing-box is separately bolted to the cover. The main bearing, figs. 497, is 3½ inches in diameter and 10½ inches long. The brasses are in two parts, upper and lower, let well into the frame, by which the horizontal thrust and pull are received; and fastened down with a flat cap, 1¾ inches thick, and four ¾-inch bolts and double-nuts.

The cylinder, figs. 498, is of cast iron, 9 inches in diameter, and 21½ inches long between the covers; comprising the stroke, 18 inches, the thickness of the piston, 3 inches, and ¼ inch of direct clearance at each end. It is bored out at each end to 9⅛ inches in diameter. It is ¾ inch thick, and has flanges 1 inch thick. The back cylinder-cover is ¾ inch thick, but is ⅞ inch at the flange. There are the ordinary three ports in a flat valve-face; the steam-ports being ¾ inch by 6 inches, and having $1/_{14}$th of the area of the piston; and the exhaust-port, 1½ inches by 6 inches, or $1/_7$th of the piston, in area. The steam-passages beyond the ports are ⅞ inch wide. The valve-face is 12 inches from the centre-line of the cylinder. The valve-chest is of the same length as the cylinder, and is of ¾-inch metal. The cover is ⅝ inch thick, joined with flanges ⅞ inch thick. The steam-pipe is 2½ inches in diameter, and the exhaust-pipe is 3 inches. The cylinder and valve-chest are clothed and lagged with mahogany.

The piston, figs. 499, is of cast iron, 3 inches thick, grooved for a packing-ring of cast iron, 1½ inches wide by $5/_{16}$ inch thick. To make the joint,

Figs. 499.—Rider Engine: Piston and Ring. Scale 1/8th.

the ring is turned to 9¼ inches in diameter, and is parted and notched out ¾ inch wide to the right and to the left, at one place. It is then sprung into its place in the piston, to the diameter 9 inches, when the notched ends lap each other and make the joint. The junk-ring is fastened flush with the centre of the piston, with four ¾-inch steel bolts and gun-metal nuts.

The piston-rod is of steel, and is 1½ inches in diameter. It is let into the piston, tapered to 1¼ inches, and secured by a steel nut 1¼ inches thick, and a $5/_{16}$-inch pin behind the nut. It is driven into the crosshead for a length of 4¼ inches, in which it tapers from 1½ inches down to 1¼ inches, and is secured by a steel cotter ⅜ inch thick and 4¾ inches long, tapered from $1 9/_{16}$ inches to $1 3/_{16}$ inches. The socket is 3½ inches in diameter. The crosshead, figs. 500, is of cold-blast cast iron. It is forked, and is 3 inches wide between the forks, which are 1½ inches thick. It carries a 1½-inch pin, which is let into each fork with a taper of ⅜ inch. The crosshead is in one piece with the upper and lower slides. These are turned to the 5-inch radius of the guides in the bed-frame, and present

sliding surfaces 6 inches wide and 10 inches long. The lower side is an adjustable slipper for taking up wear, by means of a wrought-iron wedge 2 inches wide, with a ¾-inch screw and double-nuts. The slipper is formed with flanges or ledges at the ends, by which it laps and keeps hold longitudinally of the crosshead.

The connecting-rod, figs. 501, is made of hammered scrap iron. It is 4 feet long, or 5⅓ times the length of the crank. It is 2 inches in diameter at the crank end, and is of the same diameter for half its length; the other half tapers to a diameter of 1⅝ inches at the crosshead end. The crosshead end is one forging, 3 inches wide and 4 inches deep, turned to a radius of 2 inches. An opening 2¼
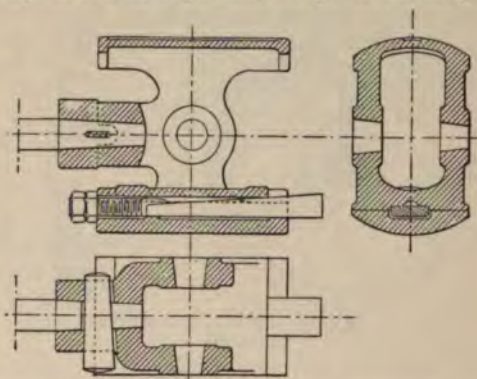
Figs. 500.—Rider Engine: Crosshead. Scale 1/10th.

inches square is formed to receive the brasses, which are of phosphor-bronze. These are bored to give a bearing 1½ inches in diameter and 3 inches long, having ⅜ inch of metal at each side of the square. They finish flush with the sides of the rod end; and one of them is formed with a fin, which fits in a corresponding slot in the end, against which a cotter ⁹/₁₆ inch thick is drawn up, by a nut and a jam-nut, on ½-inch screws. A shallow groove is cut along the top of the rod end, for lubrication, from which an oil-hole is drilled down to the bearing. Lubrication is also
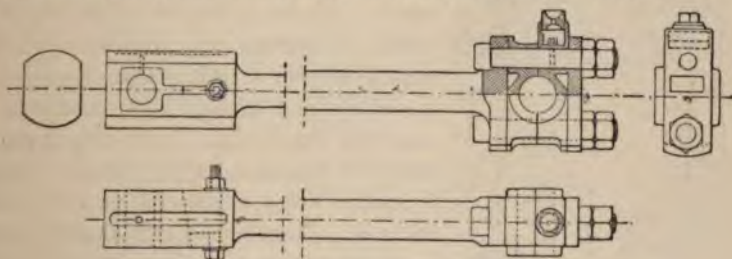
Figs. 501.—Rider Engine: Connecting-rod. Scale 1/10th.

effected by means of a lubricator fixed on the end of the crosshead pin. The larger end of the connecting-rod is constructed with a cap and bolts. The bearing is of phosphor-bronze, 2 inches in diameter and 3½ inches long, and is in two parts, together 3¼ inches long. The palm and the cap, between which the brasses are held, are 2½ inches wide by 6 inches; and they are respectively ⅞ inch and ¾ inch thick. They are held together with two 1-inch bolts and double-nuts. An oil-cup, 1⅛ inch by 2³/₁₆ inches, is cast with one of the brasses. It feeds one capillary passage, ³/₁₆ inch in diameter, and is closed by a screw-cap, having a small oil-hole drilled through it.

The main shaft, figs. 502, is of steel, 3⅝ inches in diameter throughout, and 3 feet 8½ inches in length measured from the back of the crank-disc. The journals, one at each end, are 7½ inches long; but there are no collars on the shaft. The crank-disc is of cast iron, 22½ inches in diameter and
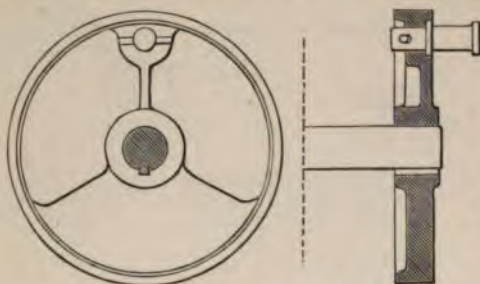
Figs. 502.—Rider Engine: Main Shaft and Crank-disc.
Scale 1/16th.

3 inches wide at the rim. The nave is 3 9/16 inches long and 6½ inches in diameter outside, showing nearly 1½ inches of metal round the shaft. It is forced on the shaft with a very slight taper, and is fixed on it with one wrought-iron key, 13/16 inch by ⅝ inch; let ⅛ inch into the shaft. It is ⅞ inch thick in the web and the rim, and is made 2¼ inches thick at the side opposed to the crank-pin, to counterbalance the portion of the connecting-rod supported on the crank-pin, and the crank-pin itself. The crank-pin is of steel, forming a journal 2 inches in diameter and 3½ inches long, with a collar at the end 2¾ inches in diameter and ½ inch thick, and another collar of the same diameter and ¼ inch thick, let into an eye in the disc. Within the disc the pin is 1⅞ inches in diameter. It is made a very tight

Figs. 503.—Rider Engine: Fly-wheel.
Scale 1/20th.

driving fit, and is secured by a ½-inch pin through the end. The eye is 4½ inches in diameter.

The fly-wheel, figs. 503, is 7 feet in diameter. It is 9 inches wide at the rim, which is turned and slightly rounded to a versed sine or rise of ¼ inch. The rim is ¾ inch thick at the edge, and 1¼ inches near the central rib. This rib, in reality the body of the rim, is 3¼ inches thick and 6 inches wide, measured to the outside of the rim. The nave of the wheel is 10 inches in diameter and 7 inches long, bored to 4½ inches in diameter. It is hollowed or enlarged, making a cavity 7 inches in diameter, and leaving 1¾ inches width of bearing on the shaft at each end of the nave. There are six straight arms, of oval section, 2⅜ inches thick, by 4¼ inches at the nave, and 3¼ inches at the rim. The wheel is fastened on the shaft with steel keys.

The eccentrics, figs. 504, for the valve-motion are of cast iron, 8⅜ inches in diameter. The main eccentric has 2 inches of throw, and the expansion eccentric has 3 inches. They have a flange at each side, 8¾ inches in

diameter, 2 inches apart for the straps, which are of cast iron, $1\frac{1}{4}$ inches thick, rounded at the outside. The eccentrics are cast in one together, and with the driving pulley for the governor, which is $13\frac{5}{8}$ inches in diameter and $2\frac{1}{4}$ inches wide, making the total thickness of the casting $7\frac{1}{4}$ inches at the nave. The joint casting is keyed on the shaft with a steel key

$\frac{7}{8}$ inch by $\frac{5}{8}$ inch, let $\frac{1}{16}$ inch into the shaft, and is further secured by a $\frac{3}{4}$-inch set-screw. The halves of the straps are bolted together with $\frac{5}{8}$-inch bolts and double-nuts through flanges or ears $1\frac{7}{8}$ inches deep. An oil-cup is cast on each strap, $1\frac{1}{4}$ inches in diameter inside, with a single capillary passage, and a gun-metal screw-cap.
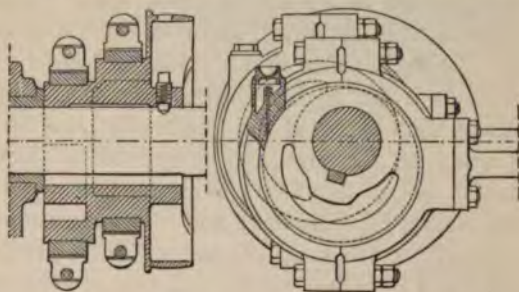
Figs. 504.—Rider Engine: Eccentrics. Scale 1/10th.

The eccentric rods are $1\frac{3}{8}$ inches in diameter at the eccentrics, $1\frac{1}{8}$ inches at the smaller end; 2 feet 11 inches long. They are joined to the straps, each with a palm 5 inches by 2 inches, and $\frac{3}{4}$ inch thick, and two $\frac{5}{8}$-inch stud-bolts and nuts.

The main valve, figs. 505, has two faces: one face is flat, and slides over the valve-face of the cylinder; the other face is concave and circular, and is traversed by the expansion-valve, which is convex and circular, and is lodged within the folds of the main valve. The main valve is three-ported,
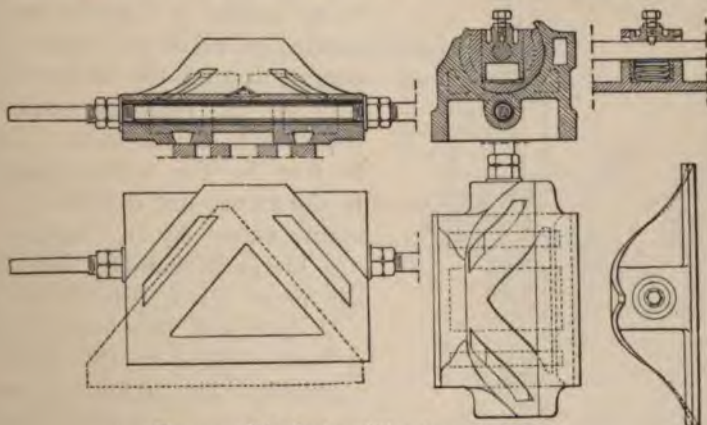
Figs. 505.—Rider Engine: Slide-valves. Scale 1/10th.

and the passages are so twisted that in the flat face the ports are at right angles to the axis of the valve, and parallel to the ports of the cylinder; whilst in the concave face they are inclined to the axis of the valve, forming, when developed into a plane surface, as shown in the figures, left-hand side, the angle 80° with each other. The expansion-valve when developed is a simple flat plate, triangular in form, the sides forming the same angle,

80°, and being parallel to the ports of the main valve. The expansion-valve, as it traverses the main valve, therefore, cuts off the steam by covering the ports, in the same way as is done by ordinary flat valves; and since the ports are inclined to the axis of motion, it follows that when the expansion-valve is turned one way on its axis, it closes the ports earlier in its travel, and cuts off steam earlier; and when turned the other way, it closes the ports later in its travel, and cuts off the steam later.

The main valve is 12⅜ inches long by 7¾ inches wide. The steam-ports in it are ¾ inch long, and the exhaust-port is 3¼ inches long. It has ¼ inch of lap at the steam-side, and ⅛ inch of exhaust-lap. Its travel is fixed at 2 inches, and it cuts off at ⅞ths, or about 90 per cent of the stroke. It is faced concavely on the upper side to 2¼ inches of radius, or 4½ inches of diameter; and the expansion-valve is correspondingly faced convexly to the same diameter. The spindles of the two valves are of steel, and are 3¼ inches apart. The main spindle is ¾ inch in diameter, and is passed through the valve. It is enlarged at each end of the valve, where it is screwed to take double-nuts. These are screwed up taut on a strut-tube of steel, previously passed over the spindle, that the valve may not be rigidly bound between the nuts. The expansion-spindle is 1¼ inches in diameter; it passes through and is fixed to a brass block 2¼ inches square, by a ½-inch set-screw inserted from above, the brass block being lodged in a square cell formed within the valve, and instrumental in communicating the reciprocations as well as the rotating movements of the spindle to the valve. The valve is free in the sense perpendicular to the travel, but it is held up to the main valve by a helical spring, 1⅞ inches in diameter, lodged within the brass block, behind the spindle. The travel of this valve is fixed at 3 inches, equal to the throw of the eccentric. The steam can be cut off at from 0 per cent to 90 per cent of the stroke.
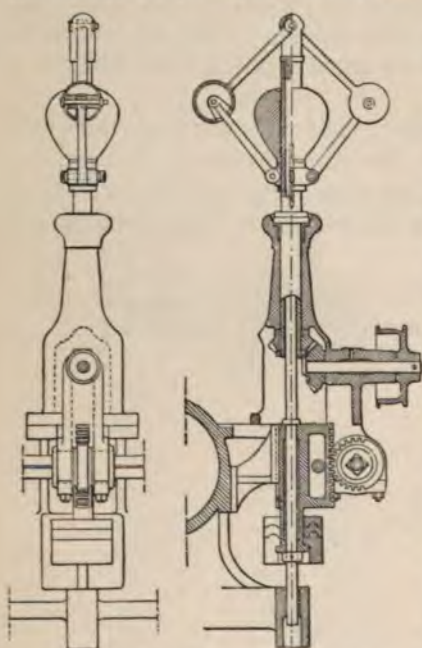
Figs. 506.—Rider Engine: Porter Governor. Scale 1/16th.

The valve spindles are guided in blind stuffing-boxes at the back of the valve-chest, and they pass through stuffing-boxes at the front, where they are both 1 inch in diameter. Outside the valve-chest, they work through a guide-block, 7 inches wide, in which they are formed up to 2½ inches in diameter. In addition, the expansion-spindle is divided into two parts intermediately between the valve-chest and the guide-block,

coupled together in such a manner that the portion pertaining to the valve-chest is free to rotate. This portion is formed square, to work through a square guide, by which means the spindle, and the expansion-valve with it, can be turned on its axis, under the control of the governor acting on the square guide. The eccentric-rods are pinned to the spindles respectively, in front of the guide-block.

The governor, figs. 506, is of the Porter type—high speed, and weighted. The balls are cast of brass, each as one piece with its suspending arm. The arms are pinned to a point in the axis of the spindle. The balls are cast hollow, and are filled with lead. They are $3\frac{1}{2}$ inches in diameter, and weigh $7\frac{1}{2}$ pounds each. The arms are $9\frac{1}{4}$ inches long measured to the centre of the balls. The balls are linked by iron rods, $8\frac{1}{8}$ inches long, to a sleeve on the spindle. The sleeve is connected to the central weight, which, with the bottom load, weigh 45 pounds. The spindle is of brass, tubular, $1\frac{5}{8}$ inches in diameter outside. It is driven through mitre-wheels at its lower end by a band from the $13\frac{5}{8}$-inch pulley on the main shaft, worked over a $6\frac{1}{4}$-inch pulley on the 1-inch horizontal shaft carrying one of the mitre-wheels; so making $\left(100 \times \frac{13\frac{5}{8}}{6\frac{1}{4}} =\right)$ 218 turns per minute. The vertical sleeve is connected through slots in the spindle to a $\frac{7}{8}$-inch rod in-side it, which passes down to and through a cast-iron sliding frame, on which

Figs. 507.—Rider Engine: Feed-pump.   Scale 1/10th.

a vertical rack is cast in one with it. The lower end of the spindle works in a brass guide. The frame is held between a collar on the rod at the upper side and a ferule fixed on the rod by a pin at the lower side; and as the rod is moved upwards and downwards by the action of the governor, the frame and the rack move up and down with it. The movement of the rack is communicated to a pinion fixed on the square part of the expan-sion-spindle, in gear with it, and the required rotary movements of the expansion-valve are effected. The spindle may be weighted at the lower end according to the speed at which it is required to run the engine.

The feed-pump, figs. 507, is single-acting, and is worked direct from the crosshead. The ram is of steel cased with brass, 1 inch in diameter, with an 18-inch stroke. It works in a cast-iron barrel, $1^{5}/_{16}$ inches in diameter inside, and fully $\frac{3}{8}$ inch thick, bolted to the frame on the inside. The

suction and delivery valves are of gun-metal, 1¼ inches in diameter; they are three-leaved disc valves, with mitre seatings and a lift of ¼ inch. They are lodged in an upright chamber at the end of the barrel, into the lower part of which the water is drawn through a ¾-inch suction-pipe, and from the upper part of which the water is discharged through a ¾-inch delivery pipe. An air-vessel of cast iron is planted on the top of the valve-chamber. It is 2¼ inches in diameter inside, and of ⅜-inch metal, and it stands 7 inches high.

The foundation for the engine, figs. 508, is a mass of brickwork capped with a 10-inch course of stone. It has a total depth of 6 feet. There are six 1-inch holding-down bolts, with plates and cotters, three at each side; for which openings, 9 inches high
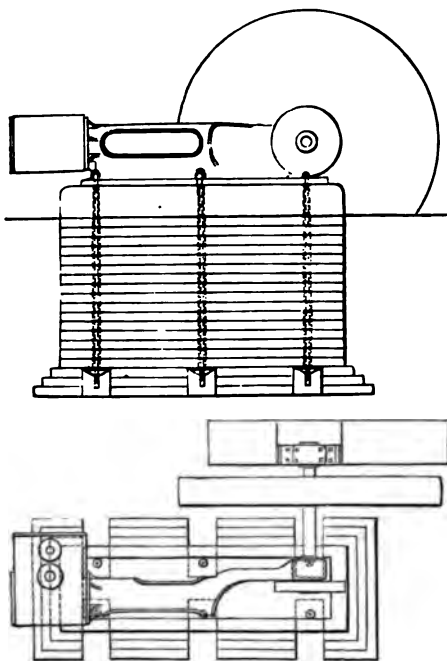
Figs. 508.—Rider Engine: Foundation. Scale 1/60th.

Hayward Tyler & Co.'s Horizontal Rider Steam Engines. 1885.

NOMINAL HORSE-POWER.............	6.	8.	10.	15.	20.	25.
Diameter of cylinder ....inches	8	9	10	12¼	14¼	16
Stroke of do. .... „	16	18	18	24	24	32
Turns per minute......................	112	100	100	75	75	56
Speed of piston per minute......feet	299	300	300	300	300	299
Diameter of steam-pipe ....inches	1¾	2½	2½	3	3½	4
Do. exhaust-pipe...... „	2½	3	3	4	4½	5½
Do. feed-pipes .... „	¾	¾	¾	1	1	1¼
Do. fly-wheel.......... „	72	84	84	96	108	120
Width of face of do............ „	8	9	9	10	10½	11
NON-CONDENSING.						
Approximate length over all...ft. ins.	10 4	11 8	11 8	14 6	15 0	18 6
Do. width „ ... „	4 4	4 9	4 9	5 5	5 6	6 2
Do. weight, packed...cwts.	37	51	55	85	95	150
CONDENSING.						
Diameter of air-pump..........inches	3	3½	3¾	4¾	5	5½
Do. injection-pipe ... „	1	1¼	1⅜	1½	1¾	2
Do. overflow-pipe.... „	2½	3	3¼	3½	3¾	4
Approximate length over all...ft. ins.	13 4	15 0	15 0	18 3	18 6	23 6
Do. width „ ... „	4 4	4 9	4 9	5 5	5 6	6 2
Do. weight, packed...cwts.	43	59	64	98	108	167
Do. do. without packing.................. „	32½	47	—	77½	—	137

and 9 inches wide, are made at the bottom of the foundation, in three courses of brick.

The weight of the 8-horse-power engine complete is 47 cwts., which includes the weight of the fly-wheel, 20 cwts. The price of the engine complete, with the feed-pump, is £110, or about £14 per nominal horse-power, or about £47 per ton weight. For holding-down bolts and plates the extra cost is £2, 5s.

The Rider engine is manufactured of various sizes of from 6 to 25 nominal horse-power. The unit of power adopted is rated as 10 circular
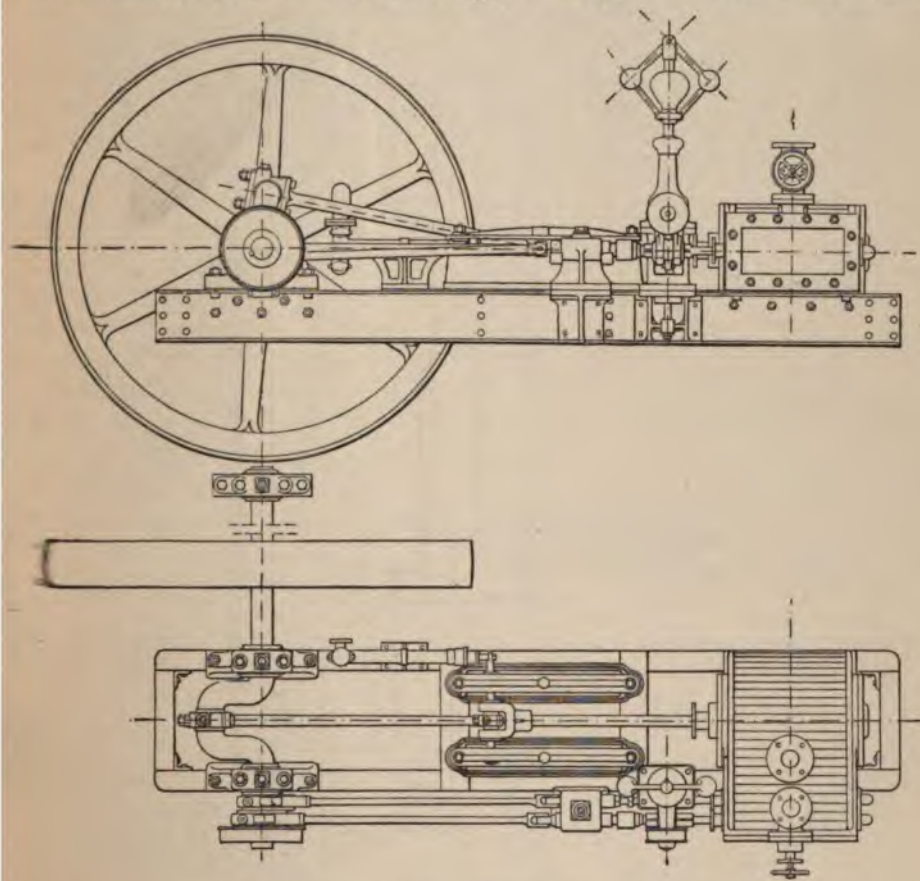
Figs. 509.—Rider Engine, designed for Foreign and Colonial Work.   Scale 1/32d.

inches of piston-area per nominal horse-power, with a speed of 300 feet of piston per minute. The indicator horse-power is from 3 times to 3½ times the nominal power, with a normal admission of 50 per cent.

The foregoing tablet gives particulars of the Rider engines constructed by Messrs. Hayward Tyler & Co.

The prices of the horizontal Rider engines, non-condensing, vary from £90 to £300, for from 6 horse-power to 25 horse-power; or from £15 to

£12 per horse-power.   For condensing engines of the same type, the prices vary from £117 to £360, or from £19, 10s. to £14, 8s. per horse-power.
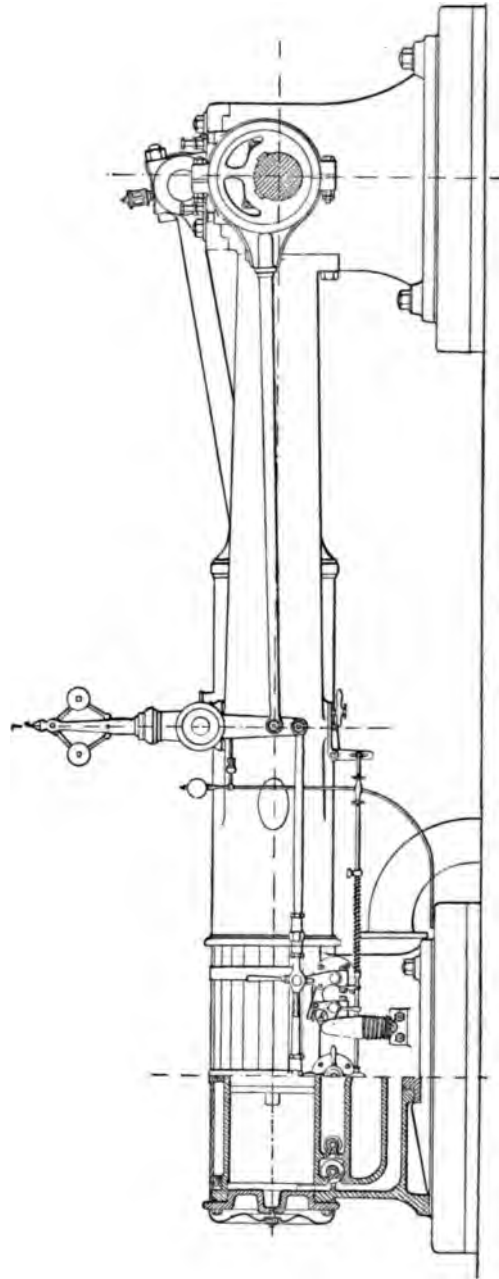
Fig. 510.—Adamson & Co.: Wheelock-Corliss Steam Engine.   Elevation.   Scale 1/36

The horizontal Rider steam engine is rearranged and constructed for foreign and colonial work, with a wrought-iron bed-frame, as in figs. 509,
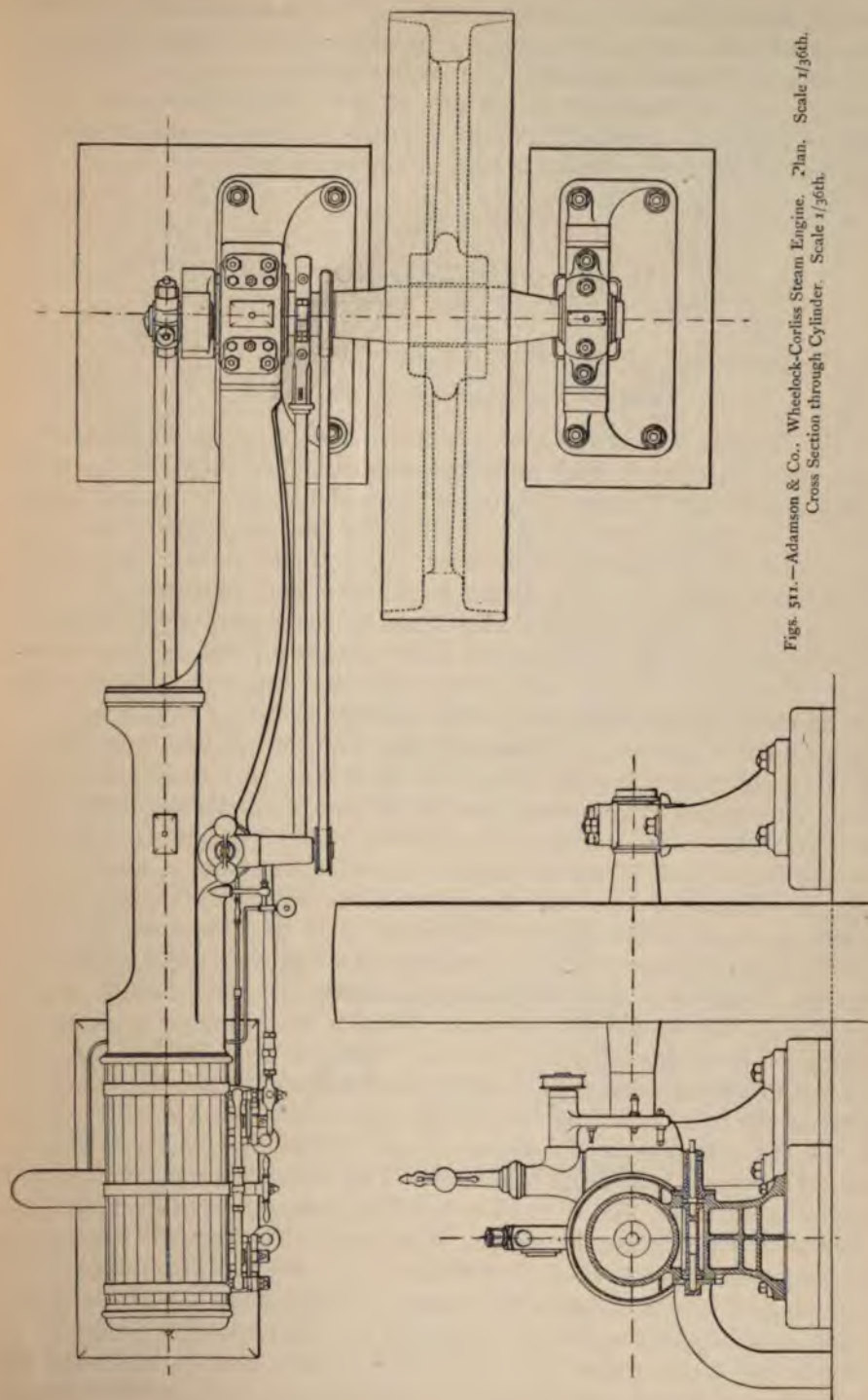
Figs. 511.—Adamson & Co., Wheelock-Corliss Steam Engine. Plan.   Scale 1/36th.
Cross Section through Cylinder.   Scale 1/36th.

showing the modified 8-horse-power engine. The framing is of girder iron, or channel iron, 9 inches deep, $3\frac{1}{4}$ inches wide, $\frac{5}{8}$ inch thick, put together with accurately planed surfaces. The main shaft is cranked, and has three bearings, two of which are placed one at each side of the crank. Two pairs of guide-bars are laid, and the pump is worked by the crosshead. The centre-line of the cylinder is $16\frac{3}{8}$ inches above the base.

CHAPTER XII.—HORIZONTAL NON-CONDENSING WHEELOCK-CORLISS STEAM ENGINE.

CONSTRUCTED BY MESSRS. DANIEL ADAMSON & CO., DUKINFIELD.

(Cylinder 16 inches diameter, 36 inches stroke.)

The Wheelock-Corliss engine embodies the principle of the Corliss valve with slip-gear, in their simplest combination, as shown in the horizontal engine, figs. 510 and 511, pages 138 and 139, of 25 nominal horse-power. The four valves are placed all at the bottom of the cylinder—in couples, one at each end of the cylinder. The extreme valve of each couple is the main valve, by which steam is admitted and exhausted from the cylinder. The other is a true Corliss steam-valve for cutting off the supply to the main valve, like an expansion slide-valve on the back of the ordinary slide. The four valves are ranged in a horizontal line, and are worked by one eccentric on the main shaft. The eccentric-rod is pinned to arms on the main-valve spindles, and communicates to them a steady reciprocating motion; and motion is taken off each of these arms by a short stirrup-link to work the steam-valve through the vertical arm of a bell-crank lever fixed on the spindle. The connections are shown in detail in figs. 512 and 513. On the upper limb of the stirrup-link a steel catch-plate is fixed, which engages with the upper corner of a square block or sleeve pivoted in a bush in the upper end of the bell-crank arm, and pulls over the arm. To keep the block in fair position to take the thrust of the catch-plate, it is traversed at right angles by a small tongue or spindle which is hinged on the pin of the stirrup, and is parallel or nearly parallel to the upper limb of the stirrup. The disengaging of the block from the catch, to free the bell-crank and valve at the right point, is effected automatically by the move-ment of the lower or curved limb of the stirrup-link over a small cam, pin, or tappet on the surface of a sleeve, otherwise cylindrical, which is loose on the valve-spindle behind the bell-crank. This sleeve is formed on its lower surface, with teeth, like a circular rack, in gear with a toothed segment pivoted on a pin below the sleeve. This segment is formed with an arm hanging downwards, to the end of which a rod connected with the governor is pinned, by means of which the tappet is shifted towards one side or the other according to the play of the governor. Correspondingly, the lower limb of the stirrup strikes the cam, earlier or later, and is lifted; and by the same movement the catch-plate on the upper limb is lifted out of

contact with the square block on the arm of the bell-crank. The valve is then immediately closed by the action of a weight, assisted by a helical spring, on the horizontal arm of the lever. The lower end of the weight is bored out, and it falls nearly air-tight on to a fixed piston, inducing a dashpot action. By the return movement of the exhaust-valve arm, the catch-plate and the square block fall together again, and the action is repeated.

All the valves are keyed on their spindles, which are of steel, hardened, and by which they are supported. The spindle of each valve is in two parts. The bearing of the outer part of the spindles is 9 inches in length, and is fitted with a steel bush ground to a steam-tight fit in the cast-iron boss by which it is supported. The use of packing is thus superseded, and a steam-tight and free-working joint is obtained. The other part of the spindle, at the inclosed end of the valve, is fixed into the cover of the valve-chamber, and projects into the end of the valve for a length of 4½ inches. The valve is bushed with har-dened steel to receive the spindle, which really acts as a pivot on which the valve turns. The valve is made slightly taper. The exhaust-valve tapers ½ inch in diameter in the length of 14½ inches; being 4½ inches in diameter at the inner end, and 4 inches at the outer end. The steam-valve is
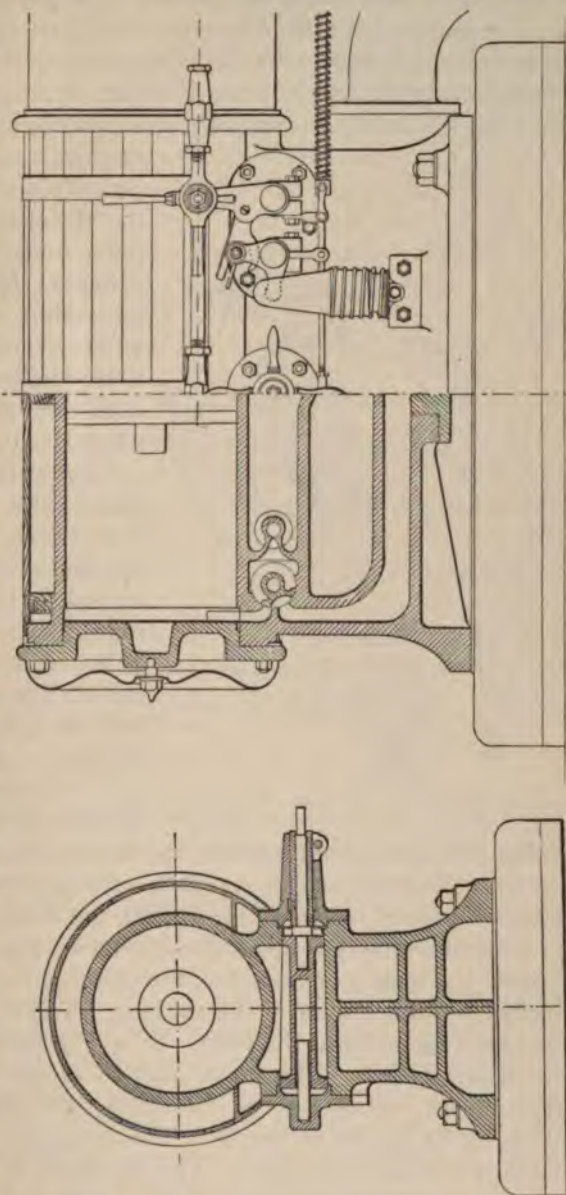
Figs. 512.—Adamson & Co.: Wheelock-Corliss Steam Engine. Detail of Cylinder. Scale 1/18th.

about 3½ inches in mean diameter. The valves are thus adjustable endwise, in the manner of a plug-tap, and may be made steam-tight without excessive pressure on their wearing surfaces. It is stated that valves thus fitted have been in use for over six years, and remain perfectly steam-tight. The main-valve arms are fastened on their spindles by screw clamps, by means of which they can be adjusted with facility.

Steam is supplied to a steam-chamber below the cylinder, extending between and including the cut-off valves, from which it is admitted to the main valves. The exhaust steam is conducted by a passage beneath the steam-chamber to the exhaust-pipe, under the front end of the cylinder. In both the valves, it may be added, the working faces are hollowed out in the middle; and thus double entrances and double exits are provided for each valve respectively.

Figs. 513.—Adamson & Co.: Trip-gear. Scale 1/6th.

The cylinder is 16 inches in diameter, with a stroke of 3 feet; and it is 1 inch in thickness. It is not steam-jacketed; it is only felted and lagged, for it is thought that the saving of fuel by steam-jacketing is overbalanced by the extra cost of the jacket. The steam-ports are 12 inches wide by ¾ inch long, having an area of about $1/_{22}$ of the area of the piston. The eccentric is 18 inches in diameter, with a throw of 6 inches, multiplied through a vibrating arm to 7 inches, which is the length of vibration of the main-valve arms. As these arms are 7 inches in length, and the valves have a mean radius of 2⅛ inches, the length of travel of the main valves circumferentially is about $(7 \times 2\frac{1}{8} \div 7 =)$ 2⅛ inches. The piston-rod is of steel, 3¼ inches in diameter; the crosshead is of steel, with a journal 3½ inches in diameter and 5 inches long. The connecting-rod is of steel, 3⅜ inches in diameter at the ends. It is 8½ feet long, or 5.67 times the length of the crank. The main shaft is of steel, 9 inches in diameter, enlarged to 11 inches for the fly-wheel; the journals are 8 inches in diameter by 14 inches in length. The crank-pin, of steel, is 5 inches in diameter and 5½ inches long. The fly-wheel is 10 feet in diameter, and 2 feet wide at the rim. The nave is 24 inches in diameter and 15 inches long; and has a circular hole 12½ inches in diameter to receive the shaft. The weight of the engine is 19 tons, of which the fly-wheel weighs 6 tons.

The nominal power of the engine, 25 horse-power, is reckoned at the rate of 10 circular inches of piston-area per horse-power. The nominal

speed is at the rate of 70 turns, or 420 feet of the piston per minute. The speed is controlled by a high-speed governor, quickened in its action by a helical spring mounted on the rod connecting the governor to the valve-gear. The governor is driven by a band from the main shaft, by which its speed of revolution is brought up to double that of the engine.

Several compound condensing steam engines of like construction, constructed by Messrs. Daniel Adamson & Co. for the Singer Manufacturing Company, Kilbowie, near Glasgow,[1] have their first and second cylinders respectively 16 inches and 28 inches in diameter, with a stroke of 3 feet; the first cylinder having the dimensions of the engine already described. The areas of the pistons are as 1 to 3.06. They are provided with a vertical air-pump and a jet-condenser. From sample indicator diagrams taken from one of the engines, it appears that the steam was cut off in the first cylinder at about 40 per cent of the stroke, at a pressure of about 83 lbs. per square inch above the atmosphere. The nominal ratio of expansion, in this instance, is $\left(\frac{100}{40} \times 3.06 = \right)$ 7.65. It is reported that at Kilbowie the engines are working with a consumption of 17 pounds of water, and $1\frac{3}{4}$ pounds of coal, per indicator horse-power per hour.

A non-condensing steam engine of the class of the engine already described is at work at the factory of Messrs. Adamson & Co., at a distance of 150 yards from the boiler, and worked in connection with a feed-water heater, causing back pressure on the piston. In one instance the engine made 80 turns, or 480 feet of piston, per minute, for a stroke of 3 feet. The steam was cut off at about $1/_{10}$th of the stroke, with an initial pressure of 64 lbs. per square inch in the cylinder. There was no sign of wiredrawing.

Chapter XIII.—PAIR OF HORIZONTAL NON-CONDENSING STEAM ENGINES, each of 10 Nominal Horse-power.

BY MESSRS. STEVENSON & CO., PRESTON.

(Cylinder 10 inches in diameter, stroke 20 inches.)

The engine, figs. 514, one of a pair, was constructed for the Army and Navy Stores, Westminster, and was erected in 1886. It has a strongly designed hollow cast-iron bed-frame, on one end of which the main pedestal is cast, and to the other end, formed as a target-end, the cylinder is bolted. The cylinder is fitted with a main slide-valve, worked direct by an eccentric, a fixed anchor plate on the back of the valve, and a pair of expansion-valves, one for each end of the cylinder, on the back of the anchor plate, worked with Stevenson & Price's automatic slip cut-off gear.

The cylinder is 10 inches in diameter, of 20 inches stroke, steam-jacketed. The steam-ports are 9 inches by $1\frac{1}{4}$ inches; the exhaust-ports 9 inches by

[1] See *The Mechanical World*, October 16, 1884.

3 inches. The jacket is one casting with the valve-chest, and a separate
working barrel is inserted. The cylinder-barrel is ¾ inch thick, the jacket
is ⅞ inch thick, inclosing a ⅝-inch steam-space; the valve-chest is 1 inch,
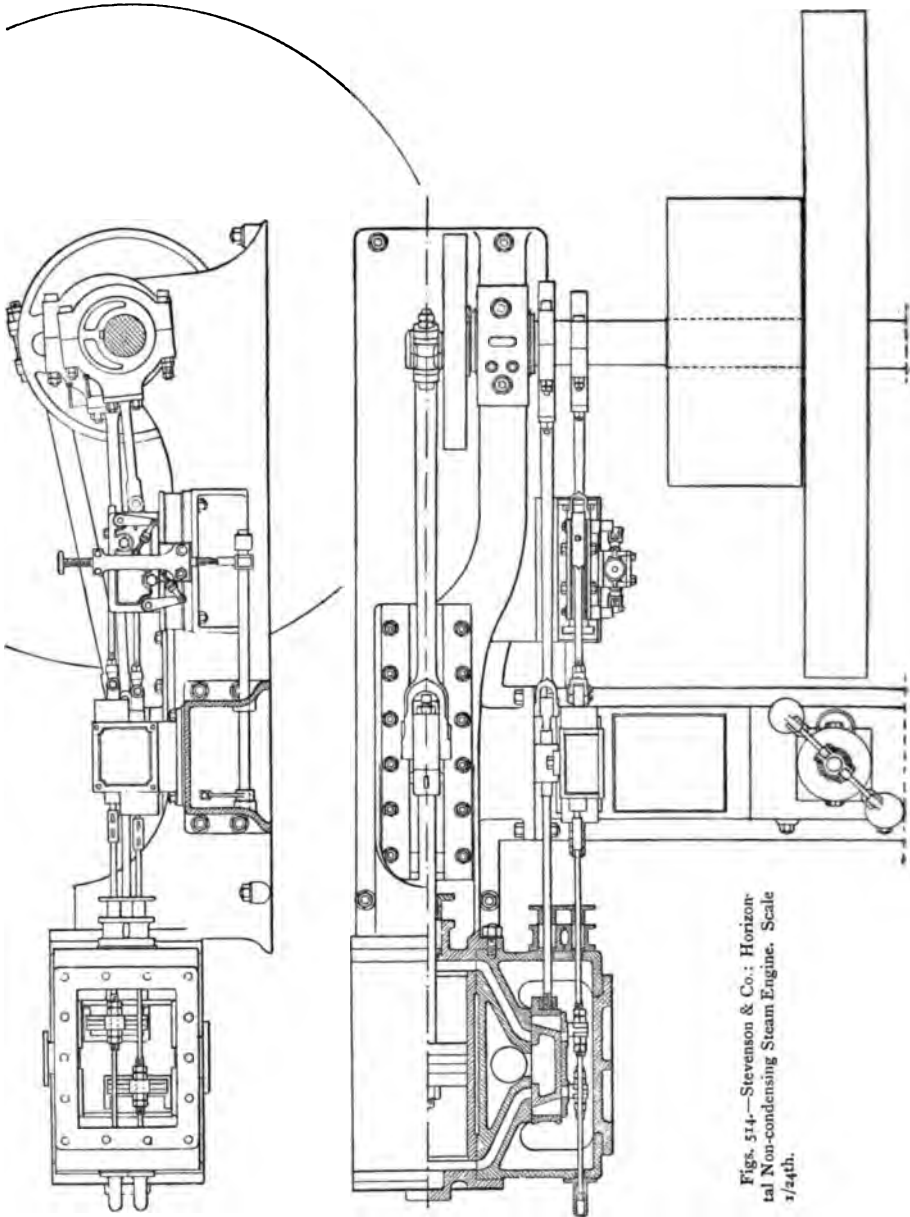
Figs. 514.—Stevenson & Co.; Horizontal Non-condensing Steam Engine. Scale 1/24th.

and the cylinder-covers 1⅛ inches thick. The front cylinder-cover is cast
in one with the frame, forming the target-end. There the cylinder is bolted
direct to the frame; and its centre-line, with that of the main bearing, is

18 inches above the level of the sole. The bed-frame, shown in section, figs. 516, is of ¾-inch metal; and is 12 inches deep midway of its length, and 18 inches wide at the sole. It develops to a width of 24 inches at the main bearing. It is fastened to the foundation with five holding bolts for each engine. The foundation for each engine is 4 feet wide, 10 feet long, 3 feet 5 inches deep.

The piston, fig. 515, is of cast iron, 5 inches thick, packed with Durham, Churchill, & Co.'s piston-rings and coil. The 2⅛-inch steel piston-rod is screwed into the piston, and fastened with a nut. The cross-head, figs. 516, is made with a slipper-slide, which works on the bed. The connecting-rod is of hammered scrap-iron, 4 feet 2 inches long, or five times the length of the crank. It is forked at the crosshead end and fitted with a cap and
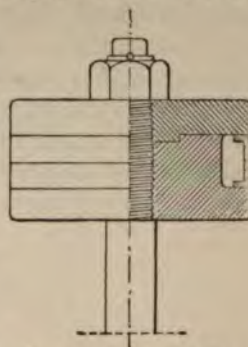
Fig. 515.—Stevenson & Co.: Piston. Scale 1/8th.
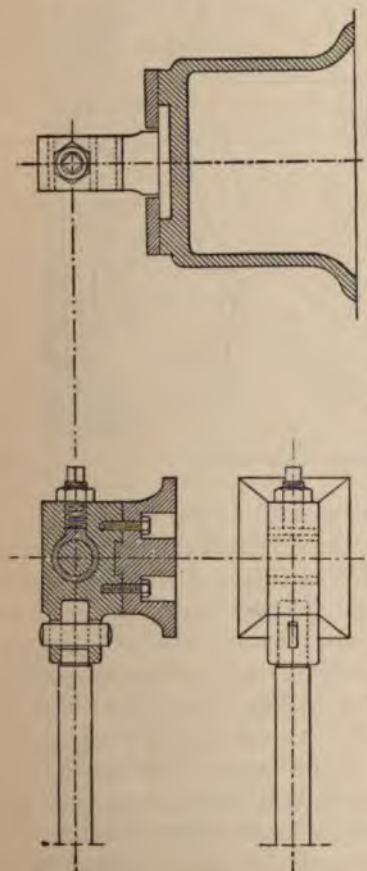
Figs. 516.—Stevenson & Co.: Crosshead and Guide. Scale 1/12th.
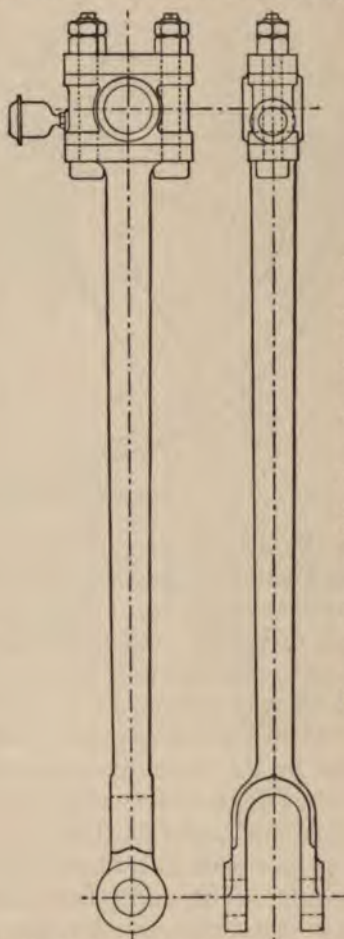
Figs. 517.—Stevenson & Co.: Connecting-rod. Scale 1/12th.

bolts at the crank end. The main shaft is of forged iron, 4¼ inches in

diameter and 8 inches long at the bearings; 6 inches in diameter in the body, on which the fly-wheel and the drum are fastened; and 5⅜ inches for the eccentrics. The fly-wheel, figs. 518, 7 feet in diameter, is bored to fit the shaft, and is secured with one steel key. The crank-disc is of cast iron, 27 inches in diameter, 3 inches wide at the rim, counterweighted so as to balance the weight of the crank-pin and of the portion of the connecting-rod which is supported on the crank-pin. The crank-pin is of steel, the journal being 3 inches in diameter and 3¾ inches long. It is cylindrical
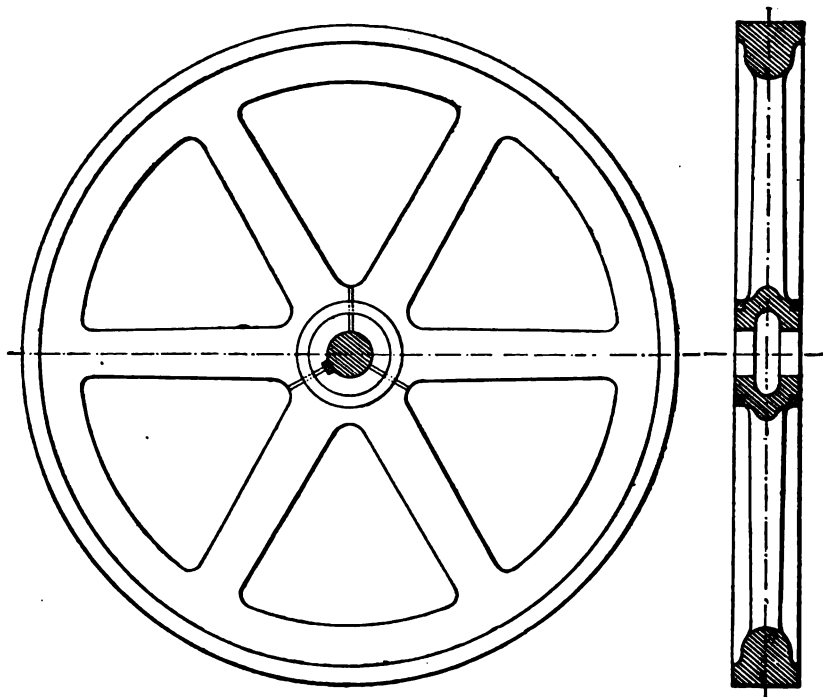
Figs. 518.—Stevenson & Co.: Fly-wheel. Scale 1/24th.

within the disc, having its collar partially recessed in the crank-face. It is shrunk upon by the disc, and fixed with a broad parallel-sided key.

The main valve has 1 inch of lap outside and ¼ inch lap inside, with 4 inches of travel. The inside lap is applied in order to secure a sufficient degree of compression for quick running. The anchor-plate is of cast iron, ⅝ inch thick; it is formed with two ports, which are duplicates, corresponding to the cylinder-ports, and are 1¼ inches by 6½ inches. These ports are commanded by the two expansion-valves, which are each 1¾ inches long, and are worked from an eccentric on the main shaft, having 2 inches of travel. With reference to the function of the anchor-plate, the manufacturers say:—
"The anchor-plate is held in fixed position by horns abutting against the valve-chest. The expansion-valves work upon the anchor-plate, which makes in fact a new cylinder face, except that it has no exhaust-port. The cut-off may be varied from 0 to ¹¹/₁₆ths of the stroke.

"With the anchor-plate, the cut-off plates are kept very light and narrow, only requiring to be equal in width to the width of port in the anchor-plate plus ¼ inch of lap on each edge. Again, with the anchor-plate, the distribution of the steam and the position of the cut-off eccentrics are independent, so to speak, of the main slide-valve. Without the anchor-plate, the conditions would be almost the same as with Meyer's expansion-plates. The cut-off plates would require to be of a width equal to the greatest distance apart of the centres of the two valves, plus the width of the port in the back of the main valve, plus the lap required on the inner edge of the plate, when released by catches, to prevent a second admission of steam. Thus, with the wider plates, the mass to be moved and the friction to be overcome by the recoil-spring would be considerably increased, necessitating stronger springs and a larger dash-pot. The throw of the expansion-eccentric and the travel of the cam-box would also be too great for making a neat arrangement."

The main-valve spindle, figs. 519, 1⅛ inches in diameter, is screwed into a nut fixed to the valve, and, passing through a stuffing-box, is guided externally in a slide bolted to the dashpots. The eccentric-rod is pinned to an eye at the end of the spindle.

The two expansion-valve spindles, ¾ inch in diameter, are each in two parts, cottered together in a sleeve. One part carries the valve between two pairs of nuts, and works in two stuffing-boxes, one at each end of the
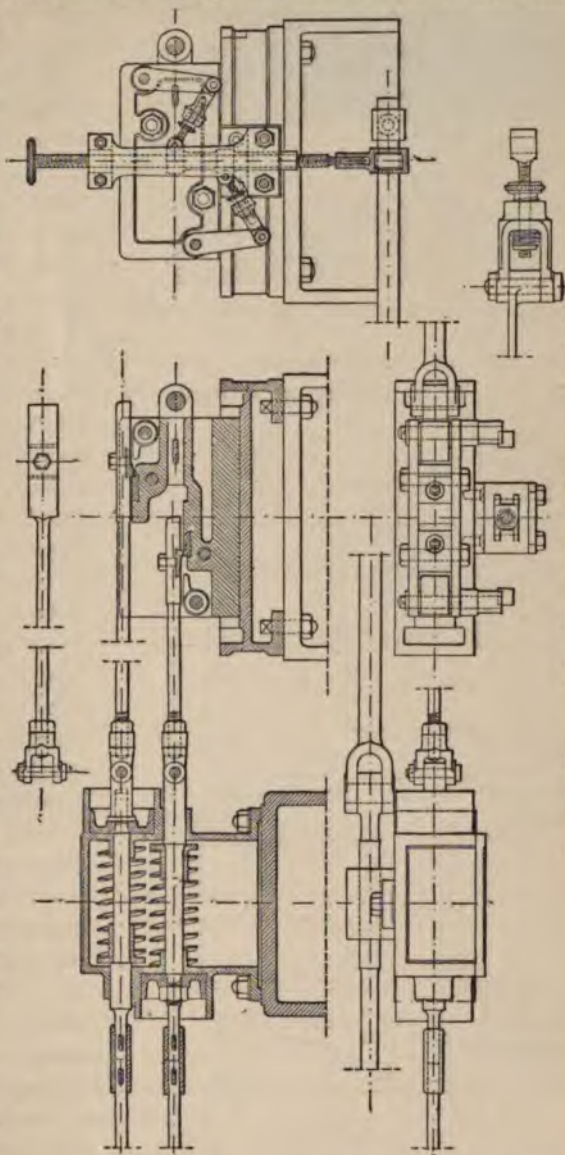
Figs. 519.—Stevenson & Co.: Valve-spindle and Trip-gear. Scale 1/10th.

valve-chest. The other part of each spindle passes through a dashpot, and is pinned to the catch-rod, by means of which the connection with the eccentric and its rod is alternately interrupted and restored within a cam-
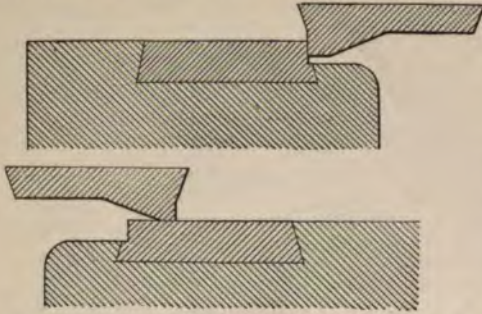
Figs. 520.—Stevenson & Co.: Detail of Catch-plates. Scale ⅛.

box. The cam-box works in guides bolted to the bed-frame; and is jointed to the eccentric-rod, through which it receives the reciprocating movement of the eccentric, equal to 2 inches of traverse. The end of each catch-rod is fitted with a steel plate, figs. 5 20, dove-tailed into its lower face, forming a notch, which engages a corresponding notched steel plate embedded in the cam-

box. The catch-rods by their own weight fall into gear with the cam-box, and the reciprocating movement is communicated to them and the
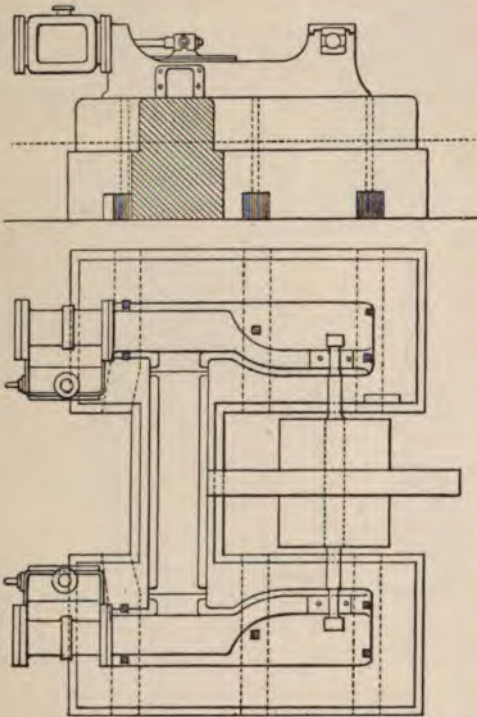
Figs. 521.—Stevenson's Engines: Foundation-beds. Scale 1/64th.

expansion-valves. Each catch-rod is lifted out of gear, for the cut-off, by means of a tappet fixed on a shaft, having its bearings in the cam-box. An arm is fixed on the end of the shaft, outside the cam-box, and is linked to an upright rod in front of the box, as shown in figs. 5 19. As the cam-box reciprocates whilst the upright rod is stationary, the tappet levers are pulled and pushed alternately, and cause the tappets to rise and fall alternately. The catch-rods in consequence also rise and fall, and are alternately engaged and disengaged with the notched plates of the cam-box. When the catch-rods are pulled or pushed, as the case may be, they compress a helical spring, 3 inches in diameter, in a dashpot, one to each catch-rod; and when they are released they are pulled over by the spring,

and by this movement the corresponding expansion-valve is closed. The recoil of the spring is softened by a piston on the same spindle, which acts by compression on a cushion of air. The spring is a coiled riband of steel, ⅝ inch by ⅛ inch in section.

The cut-off and expansion are varied by the action of the governor through a horizontal draft parallel to the bed-frame, by an arm on which the vertical governor-rod is raised or lowered, according to the change of speed. By the shifting of the rod vertically, the obliquity of the connecting-links to the tappet-levers is varied; hence also the position of these levers, and the degree of elevation of the tappets, and consequently the point of the stroke at which the catch-rods are lifted out of gear, and freed for the closing action of the springs and dashpots. When the engine is at rest, the tappet-lever connecting-links are in horizontal positions, the levers are wide apart, and the tappets depressed out of range of the catch-rod notch-plates. Means of adjustment are provided for lengthening or for shortening the catch-rods, the upright governor-rod, and the links.

The factor of safety is from 18 to 20.

The foundation is of concrete, 3 feet 5 inches deep. Each bed-frame is held by five 1⅛-inch holding-down bolts.

The normal speed of the engine is 100 turns, or 333 feet of piston, per minute. The normal working pressure in the boiler is 60 lbs. per square inch. The nominal horse-power of each engine is 10 horse-power, reckoned at the rate of 10 circular inches of piston per horse-power. At the normal speed, cutting off at 25 per cent, 52½ indicator horse-power per pair of engines is yielded, with a working pressure of 50 lbs. per square inch in the boiler; cutting off at 50 per cent, 85½ indicator horse-power is realized.

The weight of the engines is as follows:—

	Cwts.	qrs.	lbs.
Two bed-plates	29	3	14
Fly-wheel	34	1	4
Cylinders, valve-gear, pipes, &c.	80	3	10
Total weight of the pair	145	0	0; or 7¼ tons.

The price of the pair of engines is £450, or £62 per ton of weight.
The foundation of the engines is shown by figs. 521.

CHAPTER XIV.—HORIZONTAL STEAM ENGINE.

CONSTRUCTED BY MESSRS. PROELL AND SCHAROWSKY, DRESDEN.

(Cylinder 11.81 inches in diameter, stroke 23.62 inches.)

This engine, figs. 522 and 523, is constructed with a Corliss back frame, directly connecting the cylinder and the main bearing. These are supported direct on foundations. The cylinder is fitted with the Proell governor and valve-gear as applied direct to it without the intervention of ordinary slide-valves, as happens when the apparatus is applied to existing slide-valve engines, as already described, page 74.

The cylinder is 300 millimetres, or 11.81 inches, in diameter, and has a stroke of 600 millimetres, or 23.62 inches. It is steam-jacketed round the barrel. It is of cast iron 1 inch thick; the jacket is fully ¾ inch in thick-
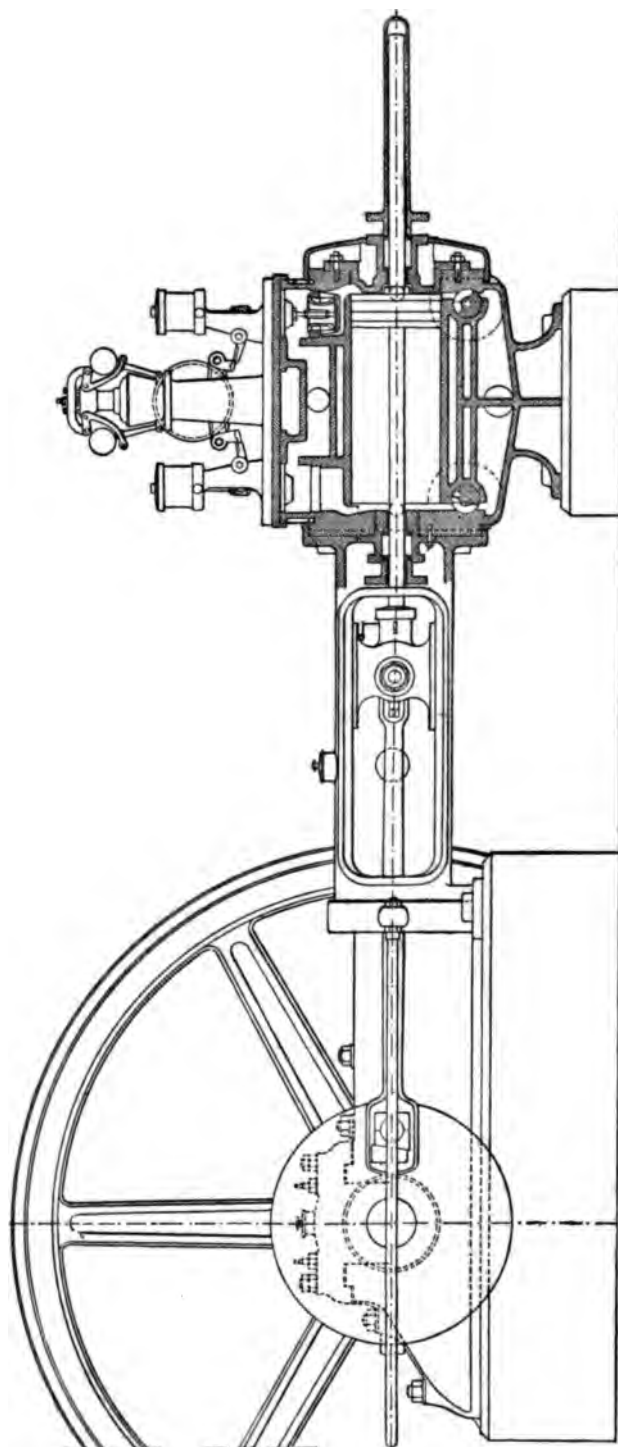
Fig. 522.—Proell and Scharowsky: Horizontal Steam Engine.   Sectional Elevation.   Scale 1/25th.
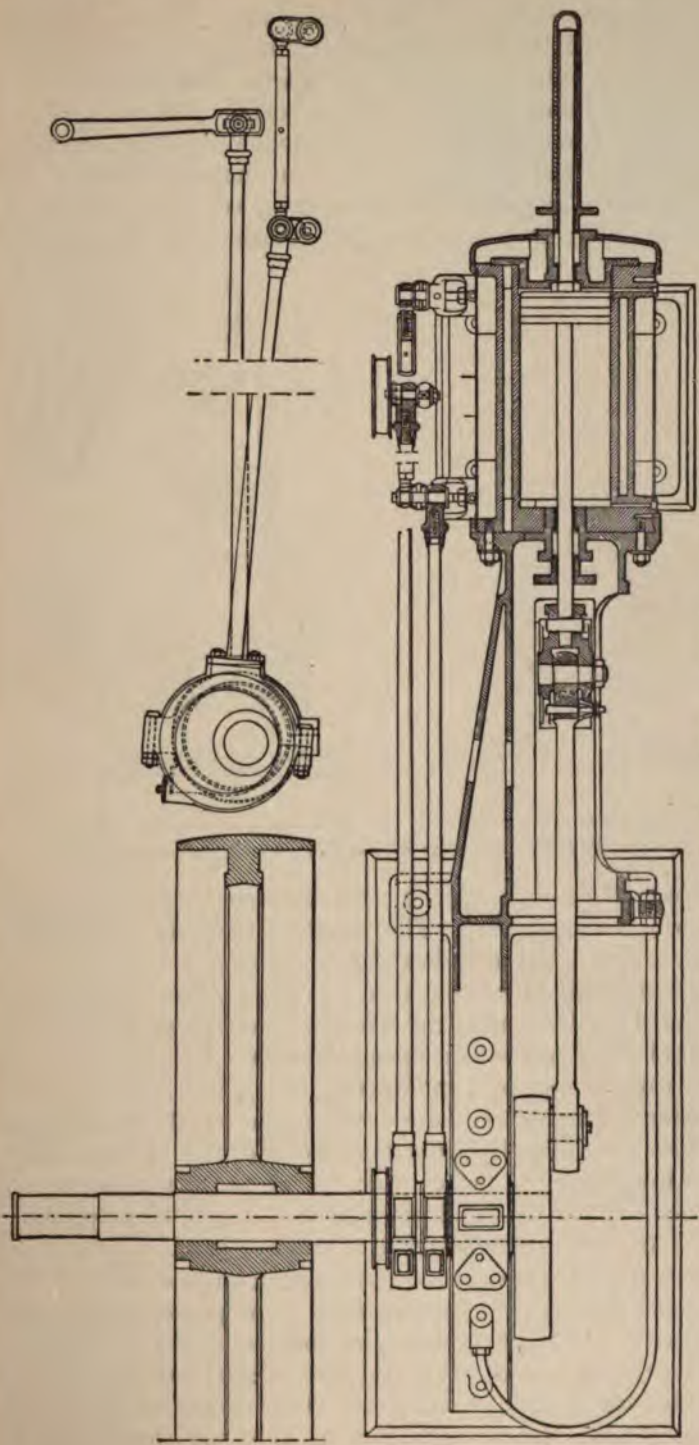
Fig. 593.—Proell and Scharowsky: Horizontal Steam Engine. Sectional Plan, with Eccentrics and Rods. Scale 1/25th.

ness, and the steam-space is 1 3/16 inches wide. The cylinder, the jacket, the valve-chest, and the base are cast in one piece. The cylinder-head is solidly fastened to the frame with six 1 ⅛-inch stud-bolts and nuts. For this purpose the frame is formed with a target-head, recessed to take the cylinder-head. The back of the frame is hollow, of ¾-inch metal: expanding in width from the cylinder-end to form the main bearing, where it is 7¼ inches wide. The guides are cast in one piece with the back, of ¾-inch metal, except where they are thickened to form the sliding surface. The
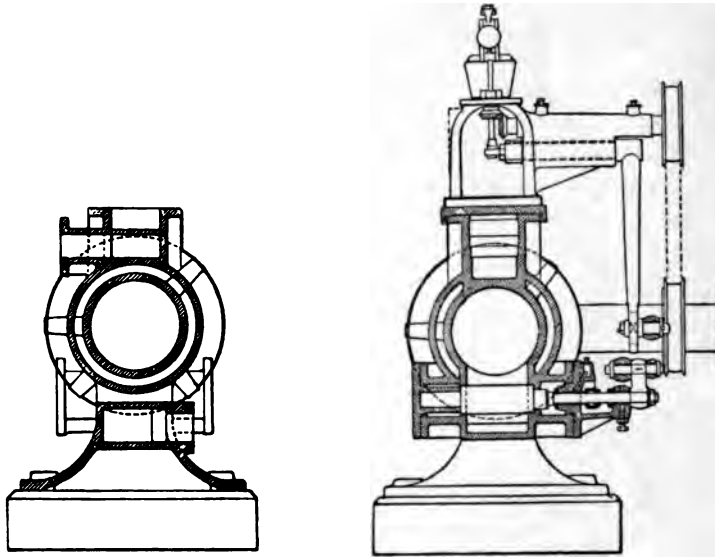
Figs. 524.—Proell and Scharowsky: Sections of Cylinder and Valve-gear. Scale 1/25th.

slides are not made adjustable, except by repacking, as they have large wearing surfaces of cast iron. The length of the frame, from the cylinder-head to the centre of the main bearing, is 7½ feet.

The piston is 4⅓ inches thick, in two pieces, the body and the cover, which, fastened together, make the recess for the packing-rings. The piston-rod is of mild steel, and is 2 inches in diameter. It is let into and through the piston, with a taper of 4 millimetres, or 5/32 inch, and a conical collar; and the piston is fastened on the rod with a gun-metal nut 2¼ inches thick, by which also the cover is screwed to the body. The two packing-rings are of cast iron, each 1⅜ inches wide, cut at one place, eccentric in form, being ⅜ inch thick at the cut, increasing to 9/16 inch thick opposite the cut. The ends of the cut are half-lapped, to make a joint. Each ring is fitted with an inner ring, similarly formed, breaking joint, and aiding by its elastic action to make the outer ring steam-tight. The piston-rod passes through and is supported in stuffing-boxes in both ends of the cylinder, and is cottered into the crosshead. It is 6¾ feet in total length. The crosshead and the slides are of steel, in one piece. It is forked to receive the end of the connecting-rod. The gudgeon is let into the crosshead with taper

bearings, and is secured by a nut and washer. The journal is about
2⅜ inches in diameter and 3⅛ inches long. The slides are 14⅛ inches in
length and 6½ inches wide.

The connecting-rod is of mild steel. It is 59 inches long, or five times
the length of the crank. Both ends are solid with the body of the rod.
The bearings are 2⅜ inches in diameter and 3⅛ inches long at the cross-
head end; and 3⅛ inches in diameter by 4⅛ inches long at the crank end.
The bushes are tightened by wedges and packing-blocks.

The crank-disc is of fine-grain cast iron, 31½ inches in diameter and
4¾ inches wide. It is counterweighted to balance the crank-pin and the
connecting-rod. It is drawn hot on to the shaft, and secured by a key.
The crank-pin is of mild steel. It has a journal 3⅛ inches in diameter and
4⅛ inches long. It is pressed into the disc, from the back, with a slight
taper, and riveted. The main shaft is 6¼ inches in diameter in the fly-
wheel, 5⅞ inches beyond the wheel; and the journals are 5⅛ inches in
diameter by 7¾ inches long. The maximum pressure on the journals is
225 pounds per square inch. The fly-wheel is 98½ inches in diameter,
having a rim 17¾ inches wide, with a slightly rounded plain surface. The
rim is of **T** section, and is 4 inches thick in the body. It is 6¼ inches
deep radially, and is 2 inches thick at each edge. The nave of the wheel
is of the same width as the rim. There are six arms, 3½ inches by
5½ inches in section at the rim; 4⅓ inches by 4¾ inches at the nave.
The wheel is keyed on the shaft.

The distribution of steam to the cylinder is effected by means of two
4-inch double-beat valves, above the cylinder, one at each end, with very
short steam-passages, figs. 522 and 524. The period of admission is con-
trolled by the Proell governor through two bell-crank levers and lifters, one
to each valve; with a spring dashpot to each. The cut-off motion is com-
municated from an eccentric of 3 inches throw on the main shaft, through
an arm 23 inches long, on the shaft of the reciprocating lever, to the end of
which the eccentric-rod is pinned, the position of the pin being adjustable
in a slot. The arms of the reciprocating lever are 5⅓ inches long, and their
vertical reciprocations are $\left(3 \times \frac{5.33}{23} =\right)$ about ¹¹/₁₆ inch in extent. The
steam is exhausted at the lower side through two Corliss valves, one at each
end of the cylinder, 2¾ inches in diameter. The spindles of these valves
are connected by an adjustable link, by means of which they reciprocate
together. Their motion is derived from a separate eccentric of 5 inches
throw. The steam is exhausted into a chamber below the cylinder, whence
it escapes by a 4-inch pipe.

The gross weight of the engine is 6 tons, including 2 tons, the weight of
the fly-wheel. The price is £166, or £27, 13s. 4d. per ton of weight. As
a condensing engine the price is £208. The engines are proportioned to
work with steam of 100 lbs. working pressure per square inch; but the
regular working pressure is 80 lbs. The regular speed is 110 turns, or
433 feet of piston, per minute. The normal cut-off is at 28 per cent of the

stroke without condensation, yielding 42 horse-power at the break; and 20 per cent with condensation, yielding 45 horse-power.

CHAPTER XV.—THE PORTER-ALLEN HORIZONTAL STEAM ENGINE.

CONSTRUCTED BY THE SOUTHWARK FOUNDRY AND MACHINE COMPANY, PHILADELPHIA.

The Porter-Allen steam engine, fig. 525, has been designed specifically for working at high speeds for long periods continuously. The length of stroke never exceeds twice the diameter of the cylinder; in the larger sizes of engine it is much less than in this ratio. The bed is specially designed for rigidity. It is constructed with a circular disc, strongly hooded, to take the end of the cylinder, which is overhung, and is bolted to it, as shown. It contains also the pedestal for the main shaft, in one piece with it. The general form of this bed was designed by Mr. C. T. Porter in 1863; and has been extensively followed by manufacturers. It is of a considerable depth, of a box form, close at the top, widened at the base, open at the bottom, having only a broad stiffening flange internally, and strongly ribbed. With the overhung position of the cylinder, clear of the bed, facility is afforded for placing the cylinder low, so that the centre-line is brought near to the surface of the bed.

The cylinder is bolted to the bed by the flange: avoiding indirect strains, and leaving the cylinder free to expand and contract in the direction of its length, on changes of temperature. There is no steam-jacket; the cylinder is lagged. The valves and valve gear—the invention of Mr. John F. Allen — combine a link-motion derived from a single eccentric, with flat slide-valves, separate movements being given to the admission-valves and the exhaust-valves. They are exemplified in the description of the next engine of Mr. Porter's, following; figs. 529, p. 160. The eccentric is placed on the shaft coincidently with the crank, and arrives at the dead-points simultaneously with it. It is, for the sake of permanency and compactness, formed in one piece with the shaft. The link is of the stationary class. It consists of a curved slotted arm, in one piece with the eccentric strap. It is pivoted in its centre-line on trunnions, which vibrate in an arc, of which the chord is equal to the throw of the eccentric, on a sustaining pin secured to the bed. The link as here shown is adapted only for running the engine in one direction. If designed for running in both directions, or reversing, the link is produced downwards, below the pivots, as much as it rises above them. A block is fitted to slide in the slot, to communicate the travel of the link to the steam-valves, through a radius-link, the length of which is the radius with which the slot is described. The travel of the block depends on its position in the link, being, when at the central position shown in the figure, just equal to
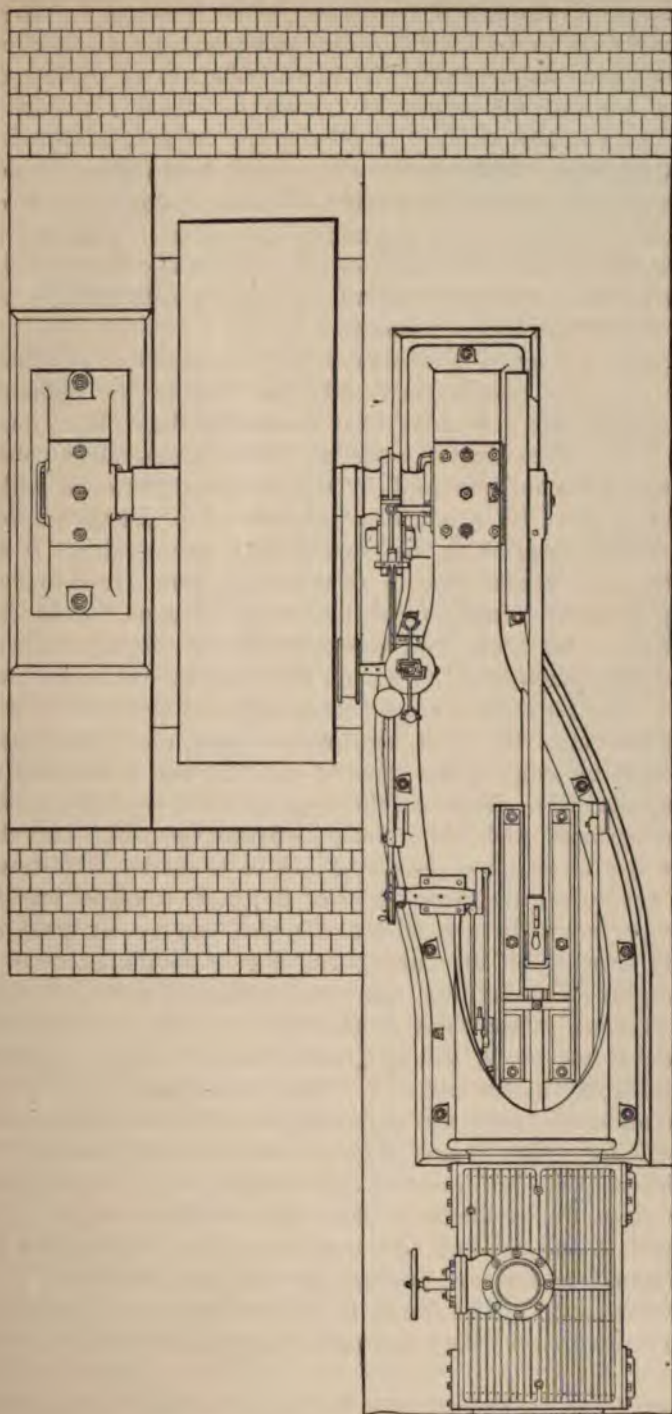
Fig. 525.—The Porter-Allen Horizontal Steam Engine. Plan.

twice the linear advance, and increasing as its position is raised. The block is controlled in position by the governor, and so the period of admission is varied as required. When the block is at the upper end of the link, the position for maximum travel, the steam is cut off at half-stroke. In special cases, as in rolling mills, the steam is admitted for five-eighths of the stroke. The exhaust-valves are driven from a fixed point at the upper end of the link, and have, of course, a constant travel, and a constant point of exhaust near the end of the stroke. The movements of this link are substantially like those of the link in the ordinary link-motion with two eccentrics, which, as before shown, are substantially the same as those of an ordinary single eccentric.

The valves are four in number, two for the admission of steam to the cylinder at one side, one at each end; and two for the exhaust of the steam at the other side, conveniently accessible by door plates, one to each valve-box. The valves are flat, on edge. The steam-valves consist each of a rectangular frame, traversed by the valve-rod, fastened with double nuts at each end. To produce a balance of pressure, an adjustable "pressure plate" is applied at the back of each steam-valve. It is formed with a cavity equal to and opposite to the steam-port. It is made hollow, and gives passage to steam longitudinally. It rests on two inclined supporting surfaces, one above and the other below; down which it moves freely under the pressure of the steam, into contact with and closing up to the valve. But its vertical movement is checked by a set-screw inserted through the bottom of the chest, bearing on a plug under the plate. It is held in position by snugs in the chest at one side, and projecting from the cover at the other side. Between these guides it is capable of moving on the inclined surfaces, and transversely between the valve and the cover, where there is a clearance of from $1/_{16}$ inch to $\frac{1}{8}$ inch. Whilst, under the pressure of the steam, the pressure-plate is forced towards and upon the valve, it is prevented by the set-screw, which can be set with precision, from unduly pressing on the valve; and thus a combination of freedom and steam-tightness is secured, and equilibrium of pressure is attained. When the pressure in the chest is exceeded by that in the cylinder, the pressure-plate is moved off the face, and a way of escape is provided for water accumulating in the cylinder. By the construction of the steam-valve in combination with the pressure-plate, four entrances are made simultaneously for steam, at two edges of each cross-bar forming the valve.

The exhaust-valves are similar to the steam-valves. Behind each valve there is an open frame, fitting a block cast on the cover, the opening of which is equal to and opposed to the exhaust-port, whilst the bars of the frame correspond to and are opposed to the seats on the valve face, on which the valve works. The frame is held to the cover by a copper diaphragm. The opening of the valve makes ample outlet for the exhausted steam.

The steam from the cylinder has access to the back of the diaphragm, and keeps the frame in contact with the valve. The pressure which in

ordinary valves is due to the port-areas, is obviated. The wear is followed up by the frame, which is permitted to close by the elasticity of the diaphragm.

The main pedestal contains "four-part" brasses, for horizontal and vertical adjustment. The brasses are lodged in a square recess in the bed. The side brasses are very long, and are held up to the shaft by broad wedges, which lie in shallow pockets, and are drawn upwards to close the brasses on the shaft, by means of the screw-bolts by which they are suspended from the cap.

The main shaft is straight, and carries a crank-disc at one end, with the crank-pin. It is so proportioned that the diameter of the journals is, in ordinary cases, one-half the diameter of the cylinder, and their length is twice their diameter. The shaft is considerably larger between the journals, and in the crank-disc. The crank is short, never exceeding the diameter of the cylinder. Part of the disc is shown in section, fig. 526, with the lubricator for the crank-pin. It is counterweighted to balance the crank, and also a proportion of the reciprocating parts of the engine, sufficient to ensure stability when the engine is running. It is specially designed to reduce the overhang of the crank and pin to a minimum. The nave of the crank-disc is brought to the face of the main bearing, and the depth of it is much less than in ordinary practice, as the reduction is made practicable by the enlargement of the shaft. Evidence of the sufficiency of the depth is given in the case of a rolling-mill service, in which no crank has given any sign of looseness.

Fig. 526.—Porter-Allen Engine: Crank-disc, Pin, and Lubricator.

The crank-pin is without a collar, and is large and short, the diameter exceeding the length; and the face of the end of the crank, against which the pin is shouldered, is sunk inwards of that of the nave, and the connecting-rod is made flat to clear the nave and the rim of the disc. The outer collar is screwed to the crank-pin. The pin is of very mild steel, case-hardened. It is rendered truly cylindrical by grinding, as well as the journals of the main shaft. The parallelism of the pin and the shaft is verified by delicate tests.

The fly-wheel and the pulley are bored and fixed in a peculiar manner. They are bored to the exact size of the shaft, and the rim is turned. Then the piece is shifted in the lathe transversely to the extent of about $1/10$ inch, and bored or cleared out to the same diameter—slotted out, in fact, removing a thin crescent-shape of material, and making the hole $1/10$ inch wider one way than the other. The keyway is then cut at the middle of this

enlargement, or, if two or three keys are to be driven, the keyways are cut symmetrically in the enlargement. In erecting the engine, the shaft can be readily threaded into the wheel, and when the keys are driven, it is bedded into the half-circle remaining of the original bore, and the wheel runs truly, and is balanced.

The piston is solid and deep, to have ample bearing on the cylinder, and to obviate the chance of seizing or jamming, if the piston becomes overheated, the piston is turned to the exact diameter of the cylinder; then its upper semicircumference is reduced by slotting by from $1/64$ inch in the smaller sizes to $1/32$ inch in the larger engines. The piston is packed with two narrow cast-iron rings, one near each end. The rings are made one piece, somewhat larger than the cylinder, are bored eccentric, cut and sprung into their grooves. They never lose their elasticity, and frequently last, it is stated, several years. They are kept in perfect contact with the cylinder, and they can only be broken ultimately by extreme pressure of steam causing a collapse. But such a contingency may be prevented by not running them over the counter bore. They are cut at the thinnest point, and the joint is kept at the bottom of the piston by a pin set in the groove between the ends of the ring. At this place the piston is steam-tight by the fact of its contact with the cylinder. The outer fillets of the piston, by which the rings are inclosed, are slightly reduced all round, in order that the steam pressure on these parts may be in equilibrium—downward pressure being thus counteracted.

Figs. 527.—Porter-Allen Engine: Crosshead and Slides.

The crosshead, figs. 527, is a solid block of cast iron; it is one piece with the slides, two in number. It is constructed in two forms, suitable for smaller and larger engines respectively, in which the piston-rod is fixed by screwing and securing with a deep jam-nut, or by tapering and cottering. The pin is of wrought iron, and is large, having upper and lower segments removed, to ensure that the brasses shall not bind on the pin. It is formed with a square at each end, by which it is fitted into the sides of the slide-blocks; and it is secured in position by a steel pin driven right through the slides and the pin. No means of adjustment is provided, as, if kept clean, it is stated the blocks do not wear.

The connecting-rod is made equal in length to six times the crank. It is made with a butt and strap joint at the smaller end, and is solid forged at the larger end. The body of the rod is flattened, and is uniformly tapered. The larger brasses are taken up by a wedge, counteracting the action of the cotter at the smaller end, and practically maintaining the length uniform.

All bearings are of Babbitt metal—of tin, antimony, and copper.   The joints of the valve gear consist of hardened steel pins in hardened steel bushes.

The speed of the engine is regulated by the Porter governor, which has been described elsewhere, page 70.   An instance of the efficient action of the governor is mentioned by the constructors.   In the Exhibition of the New England Manufacturers' and Mechanics' Institute, in Boston, in 1882, the arms of the pulley on the line-shaft, with a wrought-iron rim, flew in pieces, and the main belt was broken and fell on the floor, when the engine was exerting 100 horse-power, its full rated power.   It was observed that the speed of the engine was not sensibly accelerated for an instant.

The lubrication in this engine is automatic and continuous.   The feed is mechanical, without the use of a wick; all lubricators are stationary, and they can be supplied with oil while the engine is running.   An adjustable oil-cup is used with sight feed, which can be graduated by hand to the required rate, and can be readily shut off when the engine is stopped.   Except at the shaft-journals, the oil is taken off and conveyed to the working surfaces by the motion of the parts.   The crosshead slides, figs. 527, receive the oil from the upper guide-bar, and pass it, by four holes through it, to grooves on its lower surface, whence it is spread over the lower bars.   Oil is transferred from the stationary cups to the moving surfaces in the manner represented, figs. 528, showing the lubricator and wiper over the cross-head-pin, or the eccentric-strap.   The drop always hangs on the point; and the curved blade, at the commencement of each

Figs. 528.—Porter - Allen Engine: Lubricator.

forward stroke of the crosshead, and at the top of the throw of the eccentric, takes a particle from it, and passes it into the tube, by which it is delivered on the working surface.   The view A shows the width of the blade, and B is a cross-section of the tube and the plug by which the momentum of the drop is moderated.   The same system of lubrication is employed for the crank-pin, as shown in fig. 526.   The wiper is a broad inclined surface, the oil received on which flows radially, by centrifugal force, into the passage drilled into the crank-pin, by which it is guided to the surface.   The governor is lubricated automatically from the cup, except the counter spindle and the joints of the arms.

Sample indicator diagrams from one of these engines have been given at pages 500 and 501, vol. i., together with the results of experimental tests of performance.

A very high-speed class of Porter-Allen steam engine, figs. 529, non-condensing, having double bearings for the main shaft, was constructed to drive the armature of the steam-dynamos, at the Edison Stations, New York.   The cylinder is $11^3/_{16}$ inches in diameter, with a stroke of 16 inches. It is directly connected, and makes 350 turns, or 933 feet of piston, per minute.   The bed is forked for two shaft bearings and a double-crank, —self-contained.   The shaft has no support beyond the bearing on either

side; the crank-pin was made unusually stiff, as shown in fig. 530, to prevent deflection under the great stress to which it was to be subjected. It is provided with two flanges, one let into each crank-disc, and held by four screws; the hafts of the pin being at the same time firmly forced into the discs. The main shaft, fig. 530, is 11 inches in diameter at the journals, and
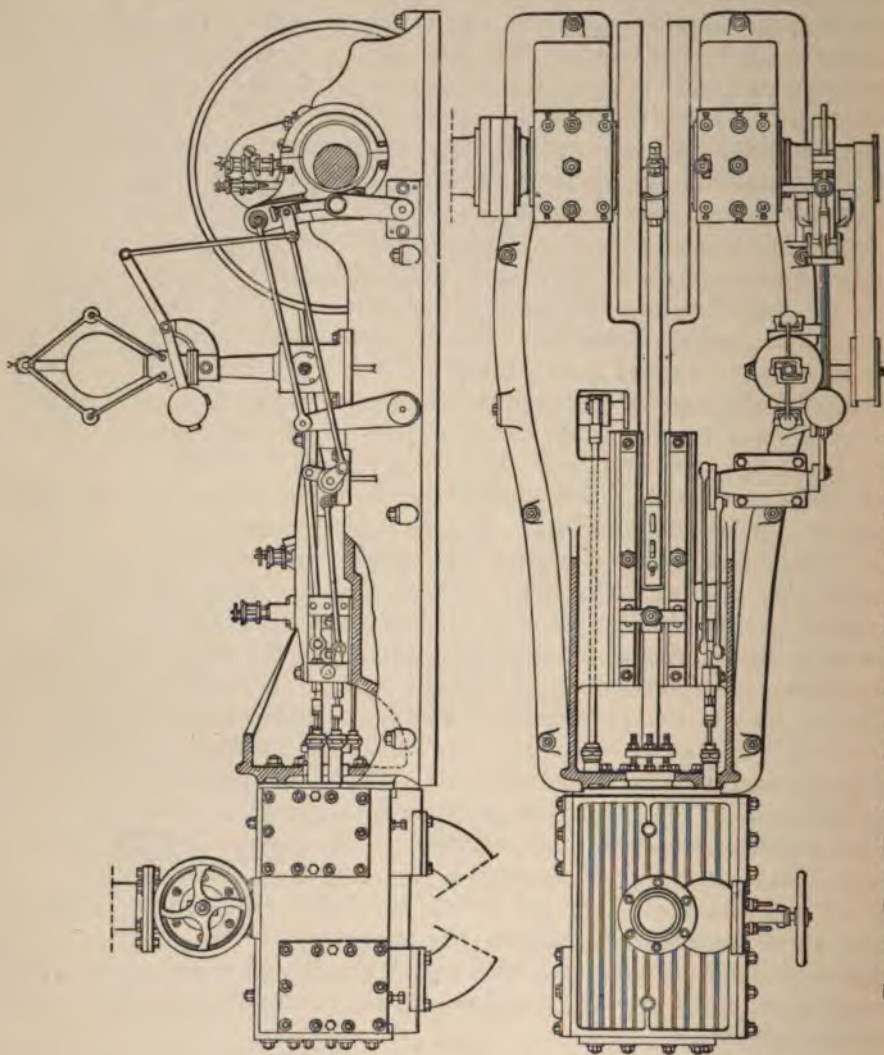
Figs. 529.—Porter-Allen Steam Engine, for very high speeds.   Scale 1/24th.

these are 21 inches in length. It is made in two pieces, keyed each into a crank-disc. The eccentric is forged solid on the shaft. The connecting-rod, fig. 531, is of steel, 4 feet long, or six times the length of the crank. The crosshead end is formed with a strap, which is fixed permanently; and the brasses are closed by a key bearing on a steel plate. The crank end was finished from a solid forging and chambered for Babbitt metal. The bolts

were then fitted, after which the end was parted, and holes were drilled for holding the metal securely.

The weight of the reciprocating parts is as follows:—

Piston, with rod, 83 pounds; cross-head, 42 pounds; connecting-rod, 109 pounds; total, 234 pounds. The counterweight was, after some trials were made, fixed at 135 pounds, or 58 per cent of the total weight, as at the crank-pin; leaving $(234 - 135 =)$ 99 pounds, or 42 per cent of reciprocating weight unbalanced. Although

Fig. 530.—Porter-Allen Engine: Double Crank. Scale 1/24th.

there was an excess of weight for vertical balance, the working steadiness of the engine was satisfactory. The force required to start the mass at

Fig. 531.—Porter-Allen Engine: Connecting-rod. Scale 1/15th.

the dead centres was 27.57 times the weight of the mass, neglecting the angular movement of the connecting-rod; equivalent to (234 pounds × 27.57 =) 6451 lbs. But, allowing for the influence of the connecting-rod, the stress was augmented to 7526 lbs., or 77 lbs. per square inch, at the dead-centre next the cylinder; and diminished to 5376 lbs., or 56 lbs. per square inch, at the centre part farthest from the cylinder. The variation is 20 per cent from the normal force.

The weight of the engine is 6450 pounds, or 2 tons 17½ cwts. The indicator diagrams,

No. 1. 350 turns per minute: Friction of Engine and Dynamo.
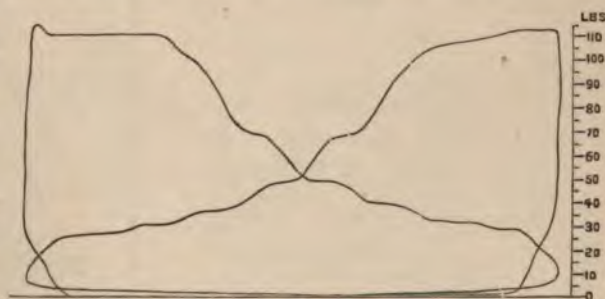
No. 2. Work in maintaining 1050 Lamps.

Figs. 532.—Porter-Allen Engine: Edison Steam Dynamo. Indicator Diagrams.

figs. 532, literally reproduced, were taken with a Tabor indicator, for a speed of 350 turns per minute. The first pair of diagrams show the frictional resistance of the engine and dynamo, requiring 13.63 horse-
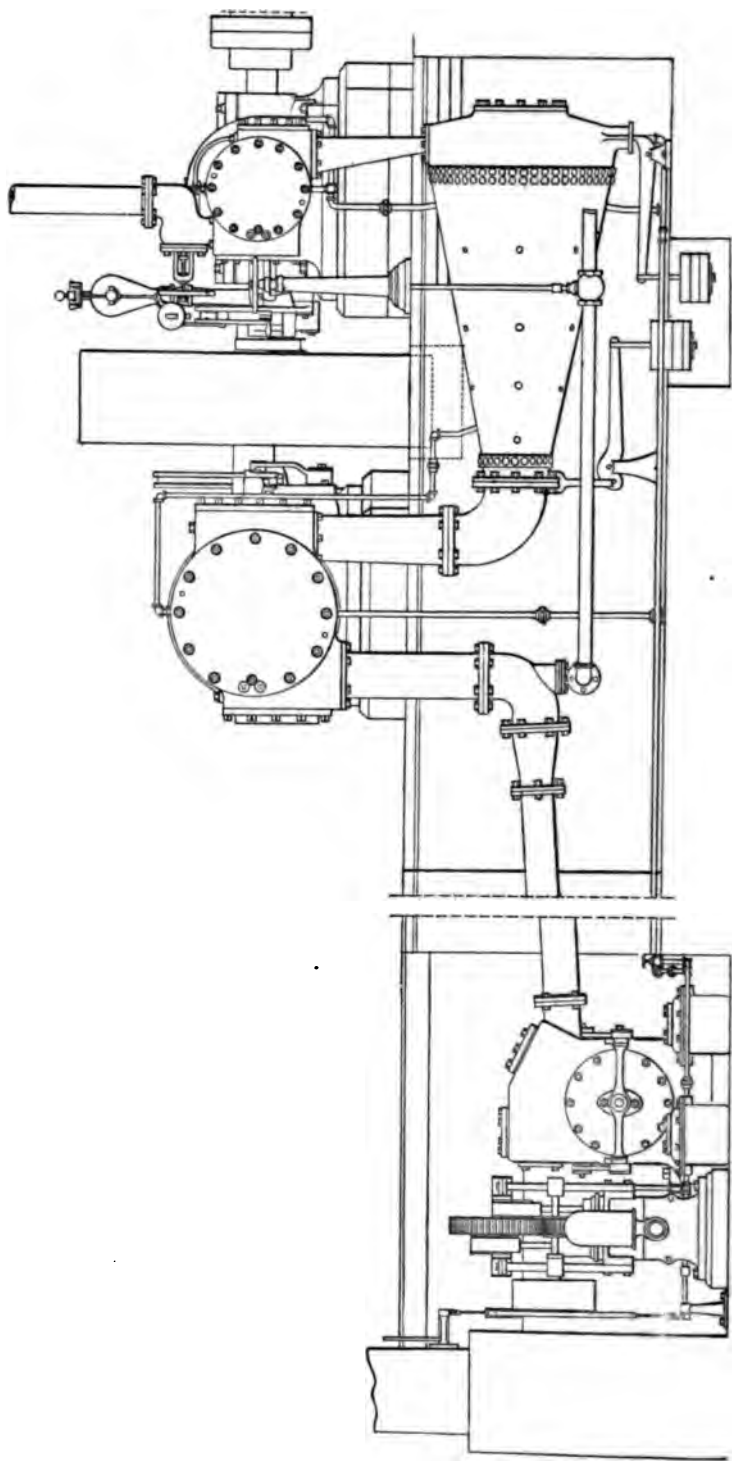
Fig. 533.—The Porter-Allen Horizontal Condensing Compound Steam Engine: End Elevation. Scale 1/38th.

ver.   The second pair show the work done in maintaining 1050 lamps,
rected for loss in conduction to 1375 lamps:—168.4 horse-power.

THE PORTER-ALLEN HORIZONTAL COMPOUND STEAM ENGINE.

(Cylinders 12 inches and 21 inches diameter, stroke 24 inches.)

In general design the Porter-Allen compound engine is like the single
ine just described.   It is shown, as constructed for a silk-mill, in end
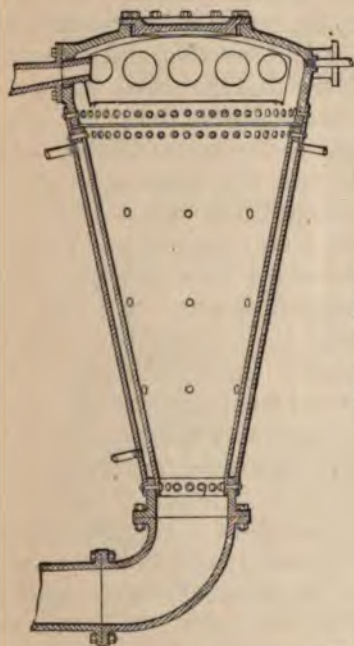
Fig. 534.—Receiver.
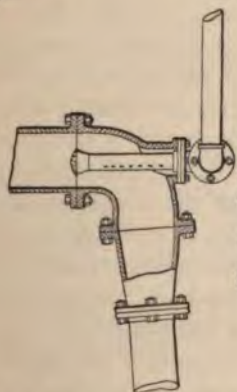
Fig. 535.—Condenser.
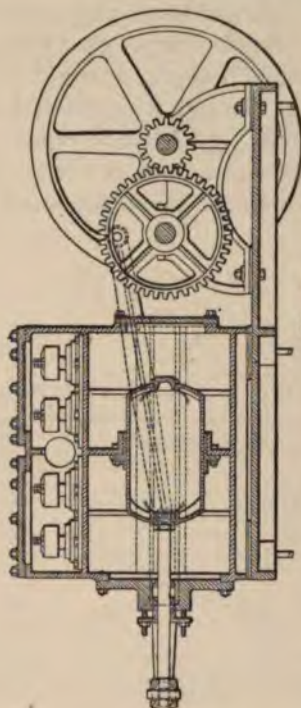
Fig. 536.

Fig. 537.

Porter-Allen Condensing Compound Engine: Receiver, Condenser, and Air-pump.   Scale 1/28th.
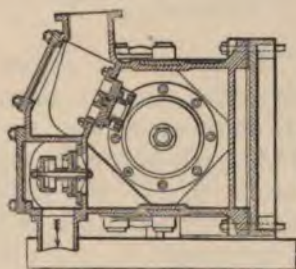
ration, in fig. 533, in which specialities of intermediate receiver, condenser,
 air-pump are represented.   These are also shown in section in figs. 534
537.   The first and second cylinders are 12 inches and 21 inches in
meter respectively, having areas in the ratio of about 1 to 3.   The
ke is 2 feet, and the working speed is 180 turns, or 720 feet of piston,

per minute. The constructors consider that 1 to 4 is a better ratio than 1 to 3. The maximum working performance is 200 indicator horse-power, with 100 lbs. per square inch of initial pressure in the cylinder. The intermediate receiver, fig. 534, is steam-jacketed. The condenser, fig. 535, is simply an injector-pipe fitted with a rose, for delivering the water as spray into the exhaust-pipe from the second cylinder, to meet and condense the steam. The water and vapour flow down a discharge-pipe into the air-pump, a line of jets of water being projected from the side of the injection-pipe down the discharge-pipe, to condense such steam as may have passed the rose. The air-pump, figs. 536 and 537, is double-acting, and consists of a 12-inch ram or plunger, closed at both ends, which reciprocates with a stroke of 30 inches, through a partition dividing the chamber of the pump into two compartments. It is made equal in weight to the water displaced by it. The suction-valves and delivery-valves are over the chamber, so arranged that the air enters above the water and is expelled before it. The valves are readily accessible. The pump is worked by a belt with gearing proportioned as 1 to 3, and makes from 40 to 80 double strokes per minute. It is capable of working up to 100 double strokes per minute.

1st Cylinder.

2d Cylinder.

Figs. 538.—The Porter-Allen Compound Steam Engine: Indicator Diagrams.

Indicator diagrams, taken from this compound engine, are illustrated by figs. 538. The sharpness of the cut-off in the first cylinder is impaired, it is said, by the passing of the steam through a long pipe from the boiler. The total clearance in the first cylinder was 6.5 per cent of the stroke; and that in the second was 8.33 per cent. Five per cent is the proportion of clearance in the engines now constructed. The steam was expanded 16 times, and the same weight of steam, it is stated, was accounted for on the diagrams, from the point of cut-off in the first cylinder to the point of exhaust in the second. It averaged 11.75 pounds per horse-power per hour. The quantity of water drained from the receiver was 50 pounds per hour, and that from the jacket was 210 pounds per hour, making together 2½ pounds per horse-power per hour; and it brought up the quantity accounted for to (11.75+2.50=) 14.25 pounds, or 77 per cent of the water pumped into the boiler, which was 18.5 pounds per horse-power per hour.
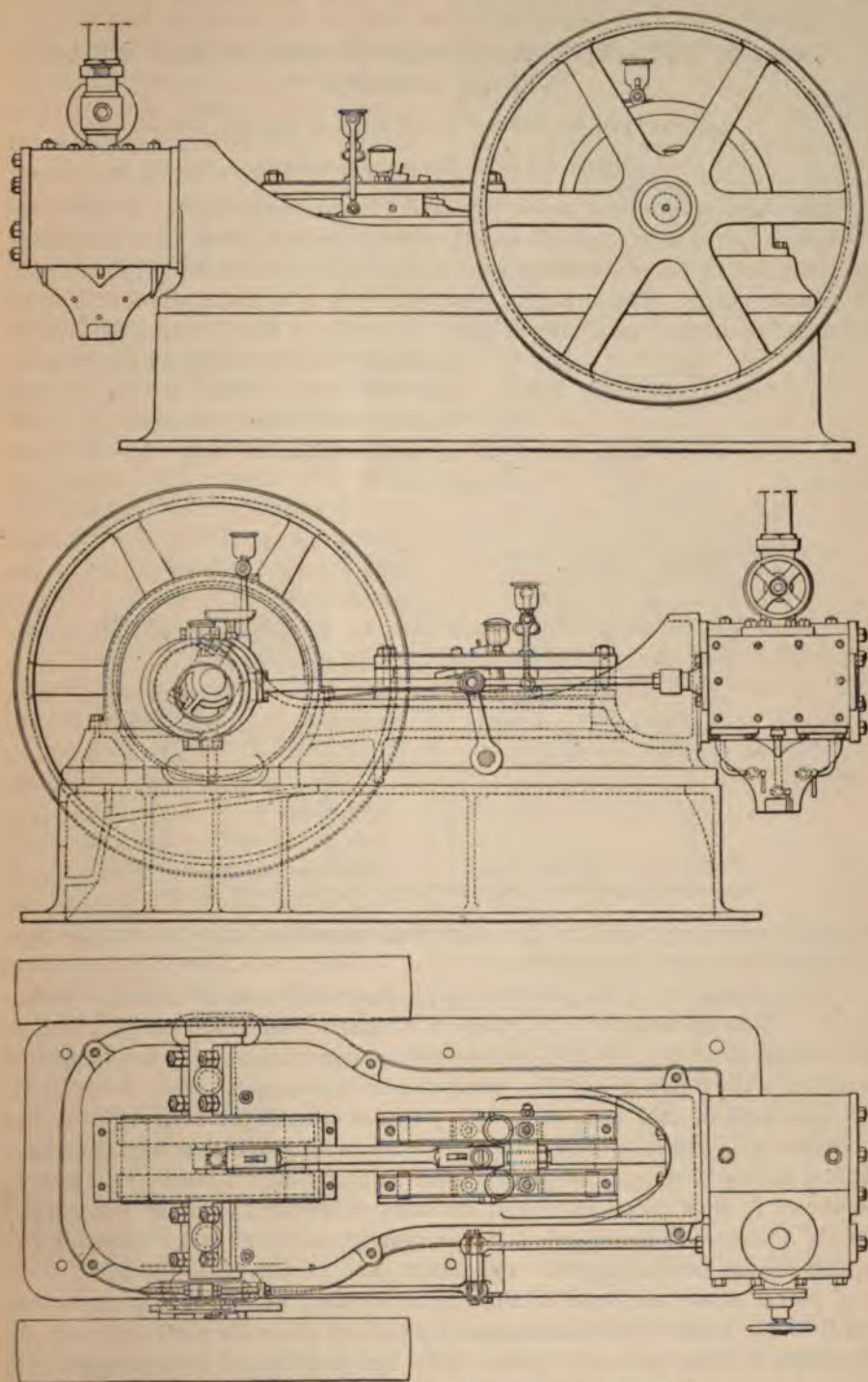
Figs. 539.—Armington-Sims Horizontal Steam Engine.   Scale 1/16th.

CHAPTER XVI.—THE ARMINGTON-SIMS HORIZONTAL STEAM ENGINE.

CONSTRUCTED BY MESSRS. GREENWOOD & BATLEY, LEEDS.

(Cylinder 6½ inches diameter, 8 inches stroke.)

The Armington-Sims steam engine is of American origin. It has been designed specifically for high speed, stiffness, compactness, and durability: specially for driving electric-light machines directly, without the intervention of counter-shafts. The stroke of the cylinder is only about one-fourth more than the diameter; and with so short a stroke, a short connecting-rod is available, with a correspondingly short and stiff bed. The bed is of the Porter-Allen type, brought up with a circular face to take the cylinder,
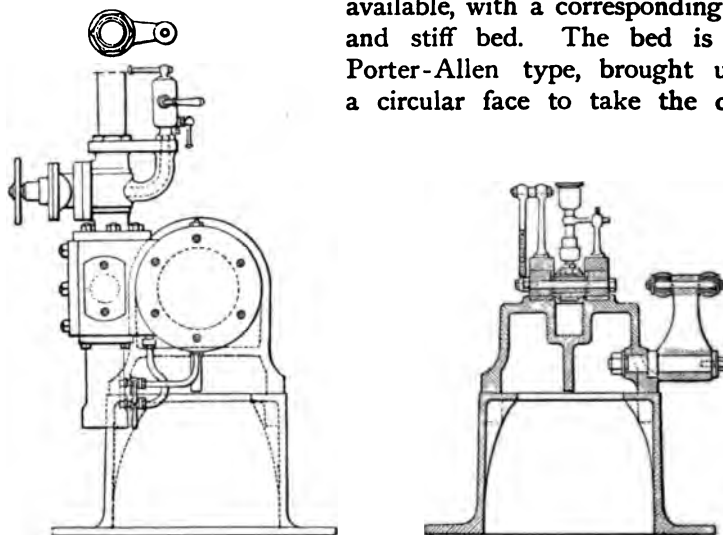
Figs. 540.—Armington-Sims Engine: End View and Transverse Section. Scale 1/16th.

which is overhung; and, at the other end, expanded laterally to give two long bearings to the main shaft.

The engine, figs. 539, 540, and 541, is described as of 18 indicator horse-power. The cylinder is 6½ inches in diameter, with a stroke of 8 inches. It makes 350 turns, or 467 feet of piston per minute. It is capable of working with steam of 100 lbs. pressure per square inch.

The bed, of cast iron, is 4 feet 5 inches long, 15 inches wide at the cylinder, 23¼ inches wide at the main shaft, and 7½ inches high, midway. It is a hollow casting, close at the upper side and open below. It is everywhere of ¾-inch metal except at its base, where the thickness is increased to 1¾ inches. It is troughed longitudinally, partly to make room for the sweep of the connecting-rod, the centre-line of the cylinder being only 1¼ inches above the level of the top of the bed, or 8¾ inches above the level of the base. The bed is open through at the main shaft between the bearings, to clear the crank-discs. The bed is stiffened by a longitudinal rib along the centre and a transverse rib at the middle.

The bed is placed on a cast-iron stool, which stands 12 inches high. The stool is ¼ inch longer and wider than the bed, and is cast of ⅝-inch metal. It is open at the top and the bottom, but is stiffened with flanges at the borders— inwards at the top, outwards at the bottom. The top is sloped under the crank-discs, to drain off the droppings. The bed is bolted to the stool with six ¾-inch bolts and nuts.

The steam cylinder, fig. 542, is of cast iron, ¾ inch thick, and is about 10 inches long between the covers: comprising the stroke, 8 inches; the piston, 1¾ inches; and about ⅛ inch of direct clearance at each end. It is fitted with a piston-valve, in a valve-chest, in one casting with the cylinder. The steam is admitted at the middle, and is exhausted at the ends of the valve-chest.

Fig. 541.—Armington-Sims Engine: Transverse Section at Main Shaft. Scale 1/16th.

There are two steam-ports to the cylinder, ⅝ inch long. They are extended right round the valve, and a perfect balance of pressure is ensured. There is no special exhaust-port, as the steam escapes directly from the ports into the ends of the chest, and thence downwards into the exhaust-pipe. The piston-valve is 2½ inches in diameter, the two ends being joined in one piece by a hollow cylinder. Each end is cleft, to form a second opening for steam to the cylinder; the steam that enters the cleft at one end, passing through the middle passage to the cleft, and thence into the port at the other end, and co-operating with the steam admitted directly into the port. By the detail of the cylinder, fig. 542, it is seen that steam is

Fig. 542.—Armington-Sims Engine   Plan of Cylinder. Scale 1/8th.

about to be admitted directly into the left-hand port, and also indirectly through the cleft at the other end of the valve and the intermediate cylinder or tube. The supplementary supply of steam by the cleft lasts only for

a fraction of the period of admission, as the delivery - cleft is promptly closed by the advancing of the valve.

The motion of the piston-valve is derived from the combined action of two eccentrics on the main shaft. One eccentric fits over and may be shifted round on the other eccentric, the other and smaller one fitting the shaft, and being free to be shifted round the shaft likewise. It is by the compounded eccentricity of the two eccentrics that the net eccentricity, and consequently the travel of the valve, are determined. The maximum travel is 2⅝ inches, and the minimum is 1 9/16 inches. The net eccentricity is varied under the action of the governor, and consequently also the cut-off and expansion in the cylinder. The normal period of admission is one-fourth of the stroke.

The action of the governor on the eccentrics may be explained with reference to the American form, illustrated by fig. 541, and 543. A wheel is fixed on the main shaft, close to the rim of which, on two of the spokes, the weights are pinned or hinged by one end. The weights are controlled by helical springs, which have a bearing on the two spokes to which they are hinged, at a little distance from the hinges, and are connected to the weights by a central bar to each, which takes hold of the end of the spring, placing it in compression. The inner eccentric and the outer eccentric are both controlled by the weights, the former being linked to them near their middles by links, and the latter being linked to one of them at the free end. By a strap over the outer eccentric, the motion is in the usual way communicated to the valve.

Fig. 543.—Armington-Sims Engine: Governor.   Scale 1/8th.

When the engine is running at maximum speed, the weights are in their outermost position, in virtue of their centrifugal force, and the springs are under maximum compression. The eccentrics have at the same time been shifted into their respective positions as shown, where it is apparent that the eccentricity of the outer eccentric is partly neutralized by that of the inner, and that the net, or active eccentricity, is measured by the interval between the centres of the shaft and the outer eccentric. The travel of the valve is equal to twice this eccentricity, and it is at its minimum when the port is only opened to the extent of the lead. When, on the contrary, the engine has its maximum load, and the speed is reduced, the weights recalled by the springs collapse, and recover the position shown in fig. 543. The eccentrics at the same time are shifted round the shaft in

opposite directions, so that their radii of eccentricity are brought more nearly together, and the resulting or net eccentricity gives maximum travel to the valve, and an admission of 70 per cent of the stroke. The lead remains practically constant.

For the small wheel of the governor, above described, the fly-wheel has been substituted in the English version. The outer eccentric is 7½ inches in diameter, the inner one is 5 inches. Their eccentricities are respectively ½ inch and 1⅜ inches.

The motion of the eccentrics is transmitted through a rocking carrier, as the eccentric-rod and the valve-spindle are not in line transversely; they are 3¾ inches apart between their axes. The carrier rocks on a 1½-inch pivot bolted to the bed; it is 6¾ inches long between centres, and carries a ⅝-inch pin driven tightly through the upper eye, the ends of the pin taking eyes on the ends of the eccentric-rod and valve-rod. The working surfaces are feruled with brass. The valve-rod is not jointed, and it springs to the slight vertical sway of the rocker.

The steam-pipe is 2 inches in diameter, and is fitted with a steam stop-valve, through which the lubricant for the cylinder is introduced. The exhaust-pipe is 2½ inches in diameter.

The piston, figs. 544, is of cast iron, 1¾ inches thick. It is hollow, and is constructed in halves, or two discs fixed together on the piston-rod, between a collar let flush into one disc, and a nut against the other disc, secured by a pin. The rod is 1⅛ inches in diameter within the piston. The discs are ⅜ inch thick, with a nave and a rim to make up the thickness. A recess is turned out of the rim to receive two packing-rings, ⅜ inch wide and ¼ inch thick, separated by a wrought-iron ring, rigidly embraced between the halves of the piston.

The piston-rod is of wrought iron, 1¼ inches in diameter, 2 feet 1¾ inches long over all. According to the original design of the crosshead, the rod is cottered with a taper into it for a depth of 2¾ inches. The crosshead and the lateral slides are of cast iron, in one piece, 2¼ inches thick and 8½ inches long, fitted with gib-plates at the lower faces of the slides, which, if wear takes

Figs. 544.—Armington-Sims Engine: Piston. Scale 1/5th.

place to any extent, can be set out with liners. The "wrist-pin" is a steel bush, 2 inches in diameter, and 2¼ inches in clear length, inserted between the slides, with a thin flange at each side, checked into the slides. The bush is held in place by a ⅞-inch steel bolt and nut, through it and the slides. The gib-plates are fastened to the slides from the top by screw-bolts, with heads let in flush.

The bolt-holes at the top are opened out, to a V shape, to the ends of the slides; and at the inner point of each opening a small hole is drilled

down to the lower surface. The oil from the oil-cup on the upper bar, being distributed over the lower surface of this bar, a portion of it is swept off by the **V** slots, and falls through upon and lubricates the lower guides.

In the English detail the piston-rod is reduced to 1⅛ inches in diameter at the end, and is screwed into the crosshead with a jam-nut, ⅞ inch thick. The crosshead proper is 2½ inches wide; the slides are 7 inches long and 1⅞ inches wide, and are fitted with brass gib-plates at the lower side for adjustments. The lower guides are formed on the top of the bed, with ledges. Above, the guide-bars are of cast iron, 2 inches wide and 1⅛ inches thick, fixed to square studs cast on the bed, with a ¾-inch stud-bolt and nut at each end. The bars are 4⅝ inches apart horizontally, between centre-lines. A brass oil-cup, 2 inches in diameter outside, is screwed into each guide-bar at the middle. The crosshead pin consists of a steel bush, 1½ inches in diameter and 3 inches long, fastened between the slides with a ⅝-inch bolt and nut.
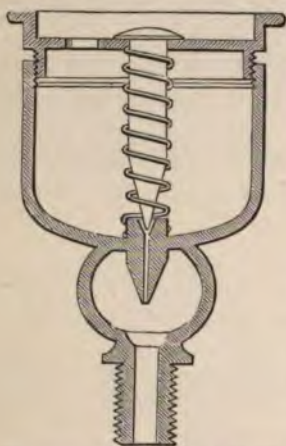
Fig. 545.—Armington-Sims Engine: Lubricator.

The connecting-rod is 24 inches long, or 6 times the length of the crank. The body of the rod is flat, ⅞ inch thick; it tapers in width from 2½ inches at the crank end to 1⅝ inches at the crosshead end. It is formed at each end with ordinary butt, strap, gib, and cotter. The bearings are 1½ inches in diameter, and 2⅝ inches long at the crosshead end; and 2½ inches in diameter by 2⅝ inches long at the crank end. Each end of the rod is lubricated from an oil-cup fixed above it, shown in section, fig. 545, as used in the American design. The supply of oil is regulated by screwing the cover up or down, and thus moving the plug into or out of the oil hole. The point from which the cup delivers the oil is exposed to view in such a way that the engineer can see at a glance how fast the oil is fed into the bearing, and by merely turning the cover between the fingers can increase or diminish it as required. To effect lubrication, the cup is mounted on a bracket, and delivers its supply of oil upon a strip of lamp-wick, which is brought just low enough so that a blade in the oil-cup, attached to the connecting-rod, wipes a drop of oil from it at each revolution.

The main shaft is cranked to a radius of 4 inches. It is 3 inches in diameter at the journals, which are next the crank-arms, and have 6¾ inches length of bearing. The crank-pin is 2½ inches in diameter and 2⅝ inches long; the arms or webs are each 2 inches thick, and circular in form transversely to the axle, being discs 7¼ inches in diameter, and they are each embraced by a counterweighted disc of cast iron, 17½ inches in diameter and 2 inches thick, keyed to the arm. The counterweight is designed to balance the crank, plus that portion of the weight

of the connecting-rod which is supported by the crank-pin, when on the dead centre. Beyond the journals the shaft carries the fly-wheels, one at each end, 2 feet 10½ inches in diameter and 5½ inches wide, with six arms. At one end the shaft is reduced to 2¾ inches in diameter, and carries the principal fly-wheel, of which the rim is ¾ inch thick, and is flanged at each side and slightly rounded. The nave is 6 inches long and 5½ inches in diameter. The spokes are 2¾ inches by 1¼ inches in section at the nave, and 2½ inches by ⅞ inch at the rim. The other and lighter fly-wheel has a plain rim ½ inch thick. The shaft is reduced by two stages—to 2¼ inches to carry eccentrics, and to 2 inches to take the fly-wheel. With two fly-wheels the engine can drive two dynamo-electric machines, one for each wheel. But the stronger wheel only is used for transmitting the whole of the power of the engine. The wheels are bored to fit the shaft, and are each secured by a feather let into the shaft, and a plate fastened to the end of the shaft with a screw.

No. 1.　Cylinder 12 inches by 12 inches, 350 turns per minute; 106.6 I.H.P.
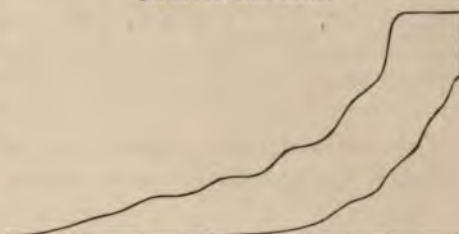
No. 2.　Cylinder 8½ inches by 10 inches, 300 turns per minute; 15.3 I.H.P.

The pedestals for the main shaft are cast in one with the base, with caps at an angle, fastened with four ¾-inch stud-bolts and jam-nuts. The bearings are lined with Babbitt metal. A circular groove round the axle is formed in the casting, at the outer end of each bearing, to

No. 3.　The same, 300 turns per minute; 36.2 I.H.P.

Figs. 546.—Armington-Sims Engine: Indicator Diagrams.

conduct away oil that may pass that way into a trough at the side of the bed. An oil-cup is fixed on each cap.

The weight of the engine is 17½ cwts., not inclusive of the stool. The price is £110, or at the rate of £126 per ton. The price of the stool is £5 extra. The similar engine, having an 8½-inch cylinder, with a stroke of 10 inches, weighs 34 cwts. without the stool; and the price is £150, or £88 per ton. The price of the stool is £8 extra.

The following tablet contains particulars of a selection of Armington-Sims engines, of powers from 6 indicator horse-power to 230 horse-power, having cylinders of from 4 inches to 20 inches in diameter. There is no

reference to nominal horse-power of the engines. The distinction of double-disc engines and single-disc engines applies simply to the employment of two discs with a cranked axle, and two bearings on the bed, as in the engine described; or of one crank-disc only when the engine has but one bearing on the bed, the other bearing being carried on a separate foundation.

Armington-Sims Steam Engines, by Messrs. Greenwood & Batley (1885).

INDICATOR HORSE-POWER, NON-CONDENSING.	6.	10.	18.	35.	60.	80.	90.	125.	150.	200.	230.
	DOUBLE-DISC ENGINES.						SINGLE-DISC ENGINES.				
Diameter of cylinder........ins.	4	5	6.5	8.5	10.5	13	12.5	14.5	16.5	18.5	20
Stroke of do. .... "	6	7	8	10	12	12	20	24	24	30	30
Turns per minute..............	400	350	350	300	275	275	180	150	150	120	120
Feet of piston per minute...ft.	400	408	467	500	550	550	600	600	600	600	600
Diameter of fly-wheel......ins.	24	30	34	40	47	47	72	78	84	108	108
Width of rim of do. .... "	3.5	4.5	5.5	8.5	10.5	11.5	15	20	24	30	30
Diameter of steam-pipe... "	1.25	1.5	2	2.5	3	3.5	4	5	5	6	6
Do. exhaust-pipe "	1.5	2	2.5	3	3.5	4	5	5	6	8	8
Length over all ....ft. ins.	4 6	5 6	6 0	7 9	9 2	9 2	13 6	15 6	16 3	19 6	19 6
Width do. ...." "	2 3	2 6	3 2	4 0	4 9	5 0	7 10	8 6	9 7	10 6	10 6

The prices of these engines vary from £70 for the 4-inch cylinder, to £875 for the 20-inch cylinder engine. The indicator power, as stated,
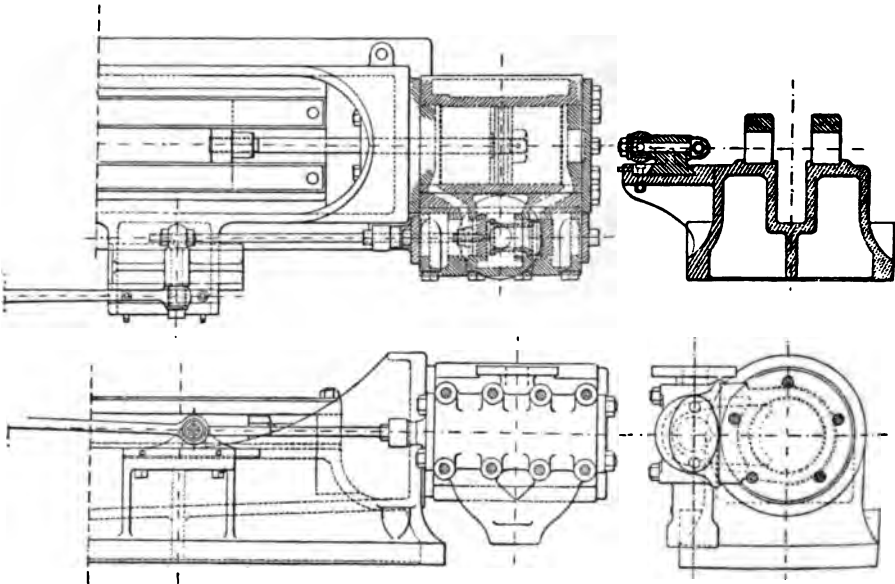
Figs. 547.—Armington-Sims Engine : Newer Design for Cylinder and Valve-chest, and for Guides for Valve-spindle. Scale 1/12th.

varies correspondingly from 6 horse-power to 230 horse-power. The price per indicator horse-power, therefore, varies from about £12 for the 4-inch engine to less than £4 for the 20-inch engine.

Indicator diagrams taken from Armington-Sims engines of various sizes show excellent action at high speeds. Figs. 546, No. 1, was taken from a 12-inch cylinder engine, of 12-inch stroke, making 350 turns per minute; and Nos. 2 and 3 were taken from an 8½-inch cylinder, of 10 inches stroke, at 300 turns per minute.

According to the most recently matured designs of Messrs. Greenwood & Batley, the valve-chest is cast separately from the cylinders, and is bolted to it, as in figs. 547. The valve-spindle is also pinned to a sliding guide, instead of the rocking lever already illustrated.

Chapter XVII.—HORIZONTAL "EXPRESS" STEAM ENGINE.

BY THE GENERAL ENGINE AND BOILER COMPANY.

(Cylinder 14 inches diameter, 24 inches stroke.)

In the "Express" engine, figs. 548, 549, and 550, the ordinary bed-plate is dispensed with, and the frame is formed of two box girders, one at each side of the engine, by both of which the cylinder is directly connected with the main-shaft bearings. There are two fly-wheels, figs. 550 and 551, between which the connecting-rod works. For this purpose the main shaft is divided into two parts, on each of which one fly-wheel separately is keyed; and the fly-wheels are connected by the crank-pin, which is keyed into an eye on each wheel. In this way the cranked shaft is solidly constructed. The counterweight required to balance the reciprocating parts of the engine is divided in halves, one of which is carried by each fly-wheel; whilst by the disposition of the fly-wheels the load on the bearings is equally distributed and compactly spaced. The stresses of the engine are, by these arrangements, symmetrically divided with reference to the centre-line, and directly resisted, and so the engine is adapted for running at high speeds.

Fig. 548.—"Express" Engine: End Elevation. Scale 1/20th.

The engine is supported by two cast-iron stools or standards, in place of the ordinary brickwork foundation, on which it is placed at a convenient height above the ground, and is rendered easily accessible below as well as above. The cylinder is overhung.
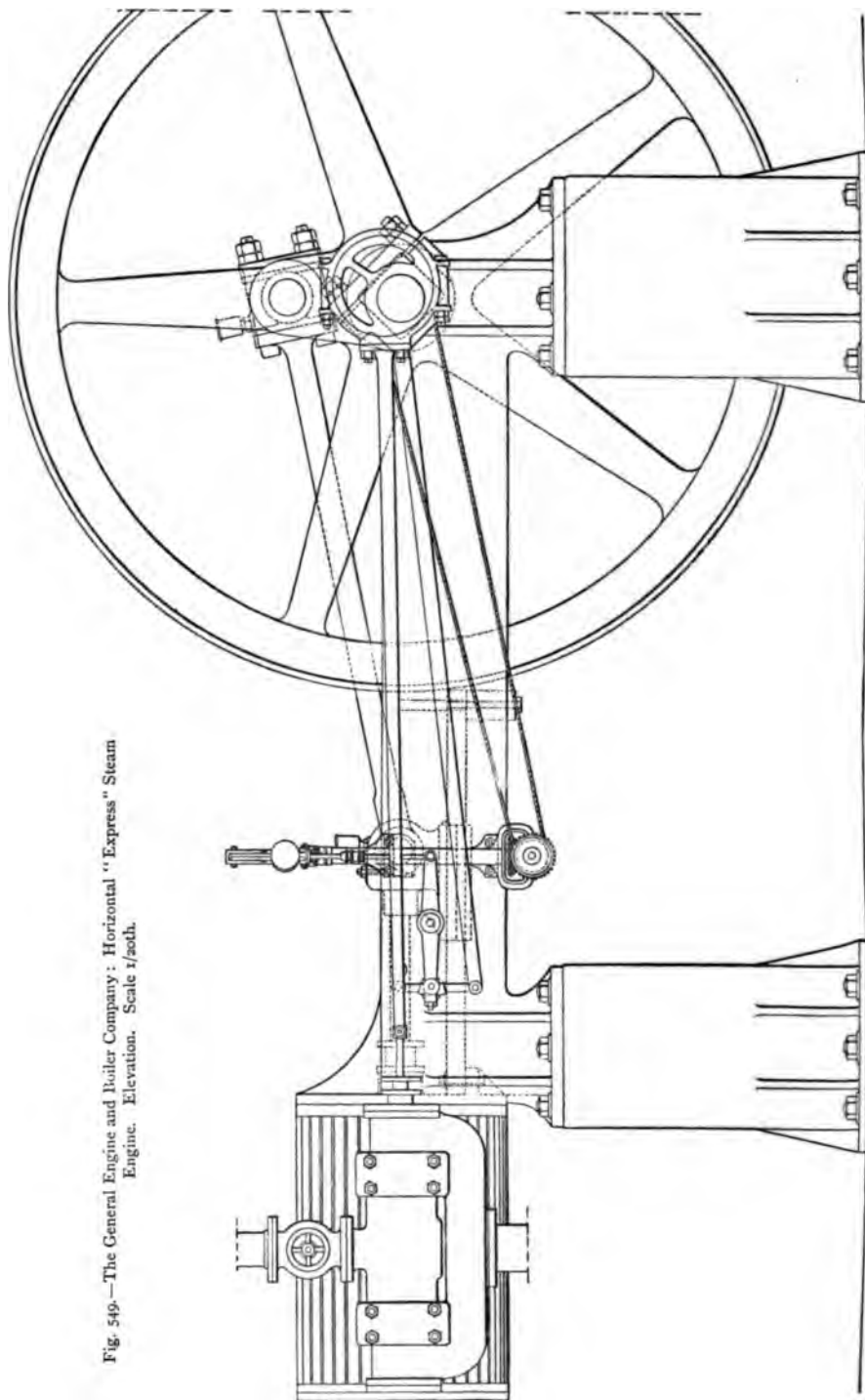
Fig. 549.—The General Engine and Boiler Company: Horizontal "Express" Steam Engine. Elevation. Scale 1/20th.
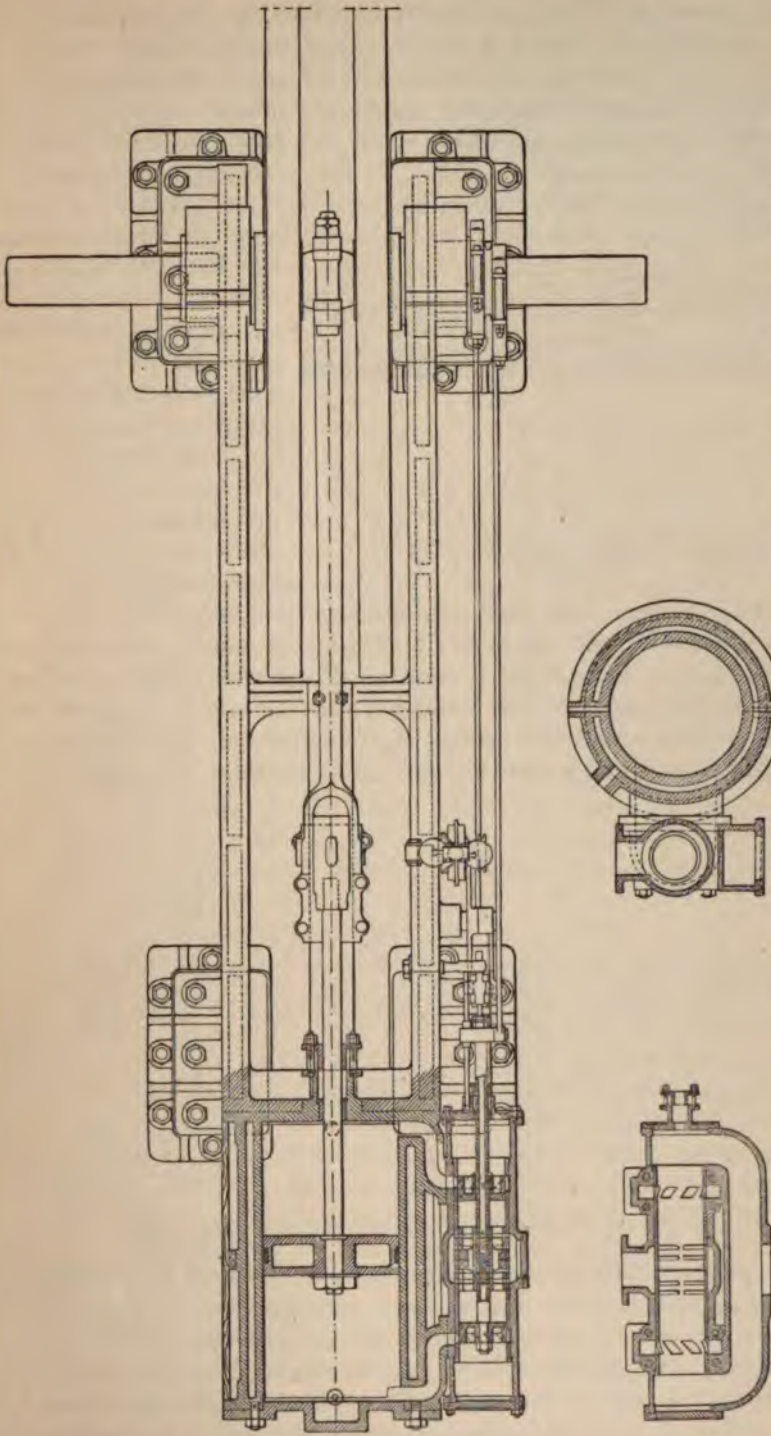
Figs. 550.—The General Engine and Boiler Company: Horizontal "Express" Steam Engine. Plan; Sections of Cylinder and Valve-chest. Scale 1/20th.

In the example of Express engine illustrated, the cylinder is 14 inches in diameter, with 24 inches of stroke. It is steam-jacketed—in the case only. The regulated speed is at the rate of 100 turns per minute, making a velocity of 400 feet of the piston per minute. The engine is of 20 nominal horse-power, for which about 10 circular inches of piston-area are given per horse-power. The indicator horse-power, with an initial pressure of 60 lbs. per square inch, cutting off for an "average rate of expansion," is about 40 horse-power. The engine weighs 5¼ tons, exclusive of the standards.
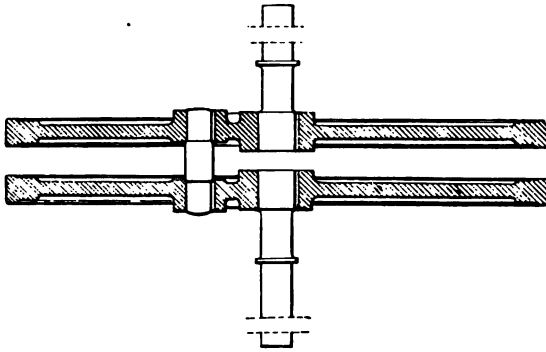
Fig. 551.—"Express" Engine: Double Fly-wheel and Shaft. Scale 1/20th.

The cylinder is cast in one piece with the jacket and the head, or front cover. The case is 1 inch in thickness, the jacket ⅞ inch, and the head 1⅛ inches. The back cylinder-cover is 1 inch thick. The steam-ports in the cylinder are 1⅜ inches by 8½ inches, making an area 1/13th of that of the piston. The steam is distributed by means of two piston-valves, of which there is one to each steam-port, sliding within a 4¾-inch steel cylinder let into a cast-iron casing of ¾-inch metal, which is fixed with eight ¾-inch bolts and nuts to the face of the cylinder. Steam is admitted
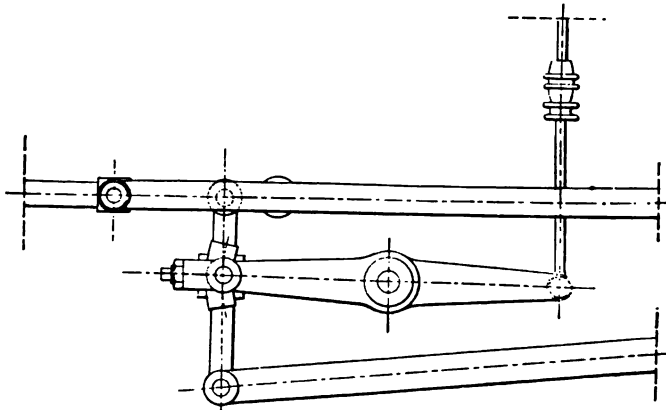
Fig. 552.—"Express" Engine: Expansion-valve Gear. Scale 1/8th.

into the valve-cylinder at the centre, through apertures which are opened and closed by the action of a gridiron variable-expansion piston-valve. The ports are opened to the exhaust by the extreme piston-valves, the steam passing into and escaping from the valve-cylinder at the ends, and being conducted through passages, rectangular in section, to the exhaust-pipe, 5 inches in diameter, which is connected below the steam-chest.

The valves are worked by two eccentrics on the main shaft; one of which works the two main piston-valves, which are fixed on a hollow rod or tube connected to the eccentric, with a travel of 4¼ inches; and the other works the expansion-valve, which is connected with and moved by a spindle, which slides within the hollow spindle of the main-valves. The travel of the expansion-valve is varied under the action of the governor by means of a lever, of which the position of the fulcrum is varied under the action of the governor, shown in fig. 552. The lever vibrates by the action of the eccentric and its rod, which is pinned to the lower end of the lever. The upper end of the lever is connected to the spindle of the expansion-valve, and the fulcrum is shifted by a lever connection under the influence of the governor. The travel of the valve is greater or less as the fulcrum is shifted lower or higher.

The frame is one casting, comprising the head, which is bolted to the cylinder-head, two box sides, and the two pedestals. The head is 1⅛ inches thick, and is fitted metal to metal to the cylinder, to which it is fastened with six 1-inch bolts and nuts. The sides are each 3 inches wide and 13 inches deep, the flanks being of ¾-inch metal. The bearings of the pedestals are inclined at the angle 45°. The pedestals are bolted to the stools with six 1⅛-inch bolts and nuts; so also is the head of the frame.

The piston is one iron casting 4 inches wide, hollow, with radial arms ¾ inch thick; around the rod, it is 1 inch thick; and at the rim, ⅞ inch thick. The packing consists of a coil of steel. The piston-rod is of steel, 2 inches in diameter, having a collar let flush into the piston, and fastened with a nut at the back of the piston. The clear length of the cylinder between the head and cover is 28½ inches, providing ¼ inch clearance space between the piston and the end of the cylinder at the beginning of each stroke. The other end of the piston-rod, reduced, is cottered into the crosshead. The crosshead is a casting, having a slipper-guide 12 inches long, sliding upon a single guide-bar, rectangular in section, 4½ inches wide and 1¾ inches deep, bolted to the head of the frame and to a transverse brace uniting the sides of the frame, with two ¾-inch bolts and nuts at each end. The brasses in the crosshead are tightened by a bolt, screwed down through the crosshead upon a wedge bearing piece, inserted behind the back brass. The connecting-rod is of steel, forked to take the crosshead-pin, and formed with a square end with two brasses and cap to take the crank-pin, fastened together with two 1½-inch bolts and double-nuts. The rod is 5 feet in length, or five times the length of the crank. The crank-pin has a bearing surface 4½ inches in diameter and 5½ inches in length between the eyes of the fly-wheels, which are bored to a diameter of 4 inches and a length of 5 inches, to receive the ends of the crank-pin, which are keyed into each fly-wheel with a steel key.

The main shaft is 5 inches in diameter, except within the fly-wheels, where it is 6 inches in diameter, with a length of 5 inches in the naves. The journals, immediately outside the naves, are each 7½ inches in length.

The fly-wheels are 7 feet in diameter, each having five arms. The rim is 3½ inches wide by 5 inches in radial depth.

The governor, fig. 553, is cross-armed, having 3½-inch balls, with a helical spring on the spindle to check the rise of the balls and aid the fall.
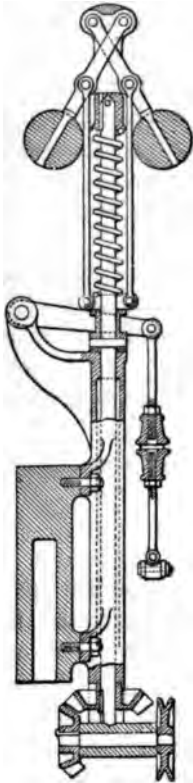
Fig. 553.—"Express" Engine: Governor.
Scale 1/10th.
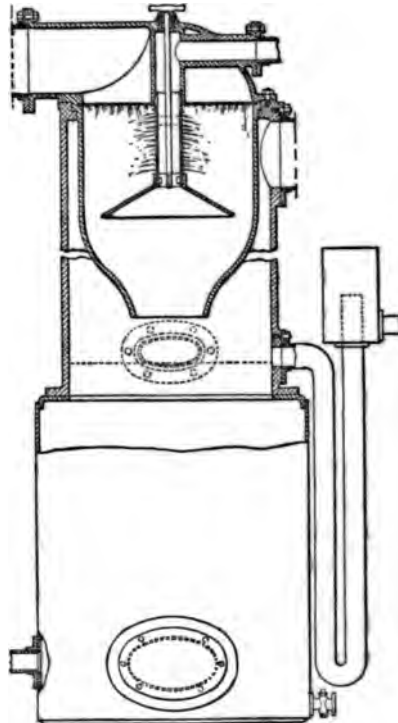
Fig. 554.—"Express" Engine: Feed-water Heater.

The feed-water heater usually employed by the General Engine and Boiler Company, is shown in fig. 554. The water enters at the upper part and falls through a perforated disc and a perforated pipe to meet the exhaust steam entering at one side. The heated water falls to the bottom and passes off at one side. Solid precipitate is removed through a man-hole. A syphon is attached, to limit the rise of the heated water in the condensing chamber.

CHAPTER XVIII.
HORIZONTAL TWIN-COMPOUND STEAM ENGINE.

CONSTRUCTED BY MESSRS. GALLOWAYS, MANCHESTER.

(Cylinders 14 inches and 24 inches diameter, 30 inches stroke.)

The "Twin-compound" Engine, figs. 555, 556, and 557, was introduced in 1872 by Messrs. Galloways; and it continues an accepted type. The first and second cylinders are side by side on one bed, and are connected to the main shaft with two cranks directly opposed to each other, so that steam is exhausted direct from the first into the second cylinder, by short straight passages. The air-pump is placed behind the second cylinder, direct on the foundation, and is worked by a prolongation of the second piston-rod.

The bed is flat on the top, and is flanged to a depth of 10 inches, making a stiff hollow casting. The two main pedestals are cast in one with it. The centre-line of the cylinder is 7½ inches above the level of the top of the bed.

The cylinders, fig. 555, are 14 inches and 24 inches in diameter, with a stroke of 2½ feet. The areas of the cylinders are as 1 to 3. The fly-wheel is 13½ feet in diameter, and 2 feet 4 inches wide at the rim. The regular speed is 65 turns, or 325 feet of piston per minute. With a boiler pressure of 80 lbs. per square inch, the engine is capable of making 125 indicator horse-power, cutting off in the first cylinder at from 40 per cent to 50 per cent,

Fig. 555.—Galloways' Engine: Cylinders, Horizontal Section.
Scale 1/24th.

according to the pressure. The range of admission is from 0 to 75 per cent of the stroke.

The slide-valves are plain flat plates, of which there are two for the admission of steam to each end of the first cylinder through short and direct passages; two for the direct admission of exhaust steam from the first to the second cylinder, and two to exhaust the steam from the second cylinder, through direct passages, to the condenser. The steam-valves for the first cylinder are worked from a small crank on a weigh shaft driven by

Fig. 556.—Galloways: Horizontal Twin-compound Steam Engine.   Side Elevation.   Scale 1/40th.
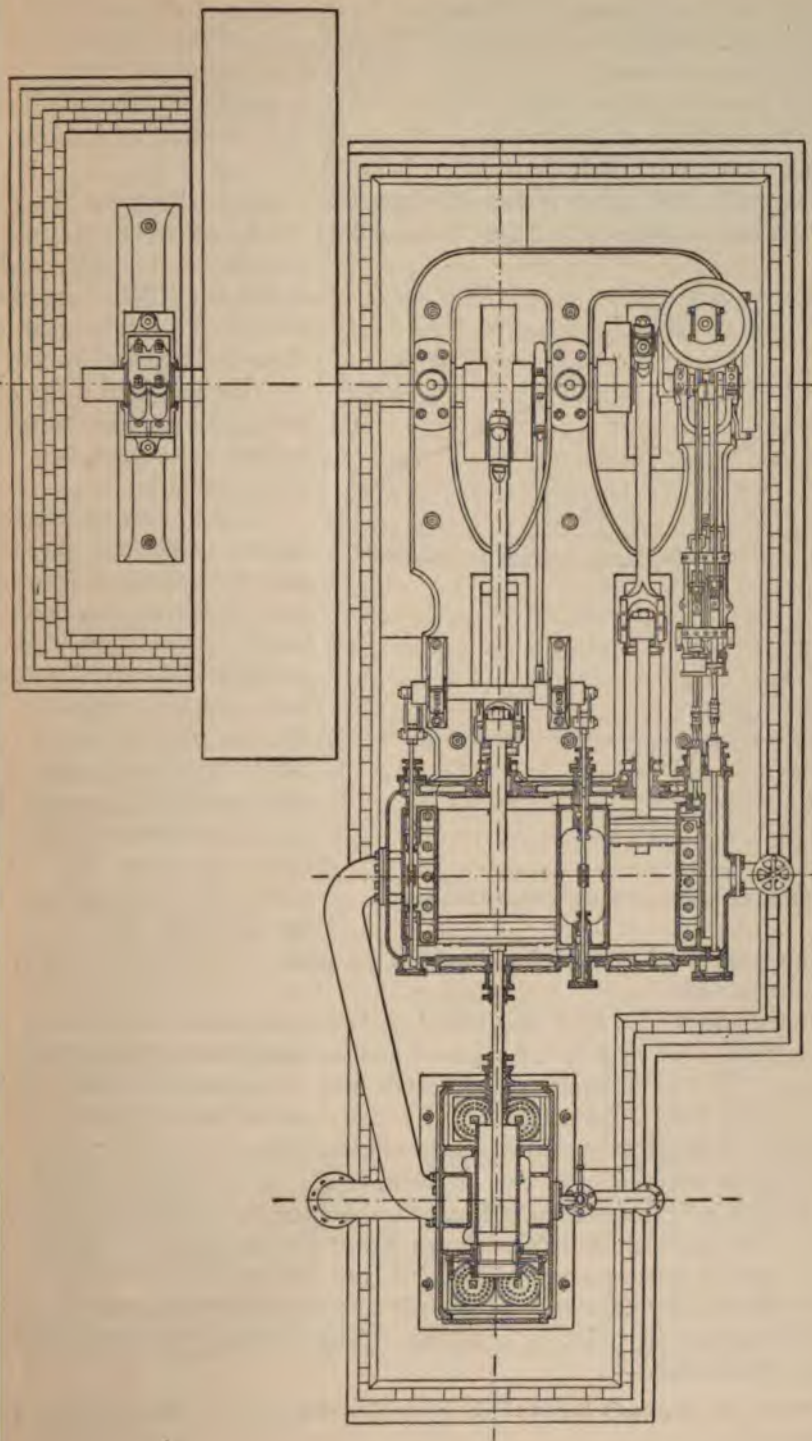
Figs. 557.—Galloways: Horizontal Twin-compound Steam Engine. Plan. Scale 1/40th.

the main crank-pin, as already described in the notice of the gear, page 34, with a slightly different arrangement. The second and third pairs of valves are worked by one eccentric, through a weigh shaft and arms.

The governor is cross-armed—approximately parabolic—and weighted. It is fitted with a cataract-box to minimize the fluctuations caused by variable resistance. It is described in page 71.

The main shaft is 7 inches in diameter, single-cranked for the first cylinder, and double-cranked for the second. The fly-wheel is 13½ feet in diameter, and 28 inches wide at the rim. The connecting-rods are 6¼ feet long, or five times the length of the cranks.

The air-pump is double-acting, 8 inches in diameter, having the stroke, 2½ feet, of the cylinders.

In their current practice, Messrs. Galloways have displaced the slip-gear for working the valves, described in pages 54 and 55; and have substituted a curved slotted-link motion, similarly to Allen's motion, page 160. They have also substituted their parabolic governor for the approximate governor, shown in page 55. The combination is illustrated by fig. 395, page 35.
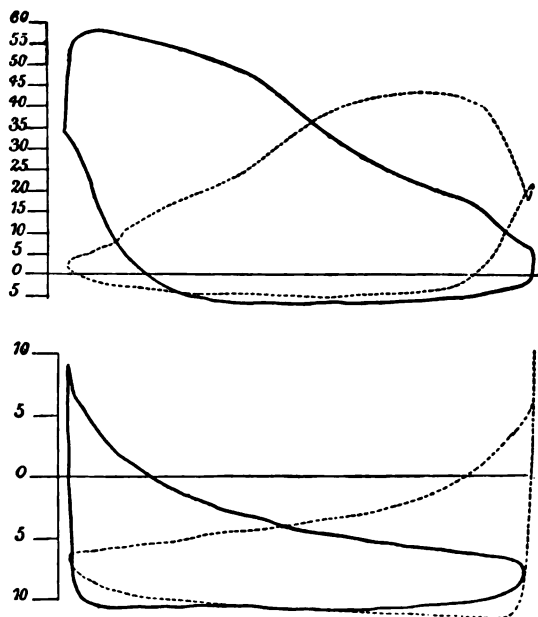
Figs. 558.—Galloways' Engine: Indicator Diagrams.

The weight of the engine is about 18 tons. The price is £965, or £53, 10s. per ton.

An engine of this type was tested on two consecutive days, during ten working hours for each test, for power and consumption of fuel and water, in 1875.[1] The cylinders were 18 inches and 30 inches in diameter, with a stroke of 3 feet. The crank of the second cylinder was 30° in advance of that of the first cylinder. The pressure in the boiler was 70 lbs. per square inch, and the average speed was 68 turns, or 408 feet of piston, per minute. The sample indicator diagrams, figs. 558, show 109.74 indicator horse-power for the first cylinder, and 66.08 horse-power for the second cylinder; together, 175.82 horse-power. They indicate imperfections of distribution which might easily have been remedied; but the performance of the engine was satisfactory in point of economy. The following were the leading results of the trials:—

[1] See the Chief Engineer's Report of The Boiler Insurance and Steam-power Company, 1876, page 32.

	1st Day.	2d Day.
Coal per hour, Oldham Black Mine, unscreened,	3.13 cwts.	2.60 cwts.
Do. per hour per square foot of fire-grate,	19.1 lbs.	15.9 lbs.
Indicator horse-power,	168.27	157.41
Coal per horse-power per hour,	2.08 lbs.	1.85 lbs.

Preparatory to the first trial, the boiler was cleaned and filled with cold water; steam was raised during the night to a pressure of 70 lbs. per square inch, with a consumption of 9 cwts. of coal. The engine was started at 6 a.m., and it was worked till 5.30 p.m., with 1½ hours interval of rest. The fires were kept at about 6 inches in thickness. On the following night the fires were lit at 3.30 a.m., and 6 cwts. of coal was consumed up to 6 a.m., when the second trial was commenced, steam having been used during the night for warming the mill. On the second day the fire was kept at a thickness of about 9 inches, the coal being charged on one side of each grate alternately at regular intervals, with a nearly entire absence of smoke and a saving of fuel. The feed-water was heated by one of Green's economizers, consisting of 120 pipes 4 inches in diameter, 9 feet long.

The boiler was tested next, in two trials of 10 hours each. It was a Galloway boiler, 24 feet long by 7 feet in diameter, with two 2¾-feet furnace-tubes and 24 conical water-tubes. The grates were 3 feet 4 inches long. The same system of firing was adopted as in the second trial of the engine—alternate side-firing, and from 8 inches to 10 inches thickness of fire. The disc-ventilator in the door was open for a short time after each charge, and smoke was effectually prevented. The steam escaped into the atmosphere through a 4-inch pipe. The coal used for the first trial was Oldham Black Mine, and for the second trial a similar mixture from the Worsley district was used. The area of fire-grate was 18.3 square feet.

	1st Day.	2d Day.
Coal per hour,	Oldham, 2.60 cwts.	Worsley, 2.60 cwts.
Do. do. per square foot of fire-grate,	15.9 lbs.	15.9 lbs.
Ash,	9.7 per cent.	7.7 per cent.
Temperature of feed-water,	109.9° F.	109.6° F.
Water evaporated per hour,	38.70 cu. ft.	40.84 cu. ft.
Water per pound of coal,	8.23 lbs.	8.69 lbs.
Do. do. from and at 212° F. (equivalent quantity),	9.18 „	9.75 „

Applying the actual rate of evaporation, 8.23 pounds per pound of Oldham coal, to the consumption of the same kind of coal, 1.85 pounds per horse-power per hour, by the engine, the water consumed per horse-power per hour was ($8.23 \times 1.85 =$) 15.22 pounds.[1]

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[1] In the Report, the water consumed per horse-power per hour is calculated in terms of 9.18 pounds of water from and at 212° F. per pound of coal, and is stated to be equal to ($9.18 \times 1.85 =$) 16.98 pounds. But, in such a calculation, the actual quantity of water consumed—8.23 pounds—is the proper factor.

CHAPTER XIX.—HORIZONTAL COMPOUND CONDENSING STEAM ENGINE, OF 50 NOMINAL HORSE-POWER.

CONSTRUCTED BY MESSRS. DAVEY, PAXMAN, & CO., COLCHESTER.

(Cylinders 13 inches and 22½ inches diameter, 24 inches stroke.)

According to the design of this engine, shown in elevation and plan in figs. 559 and 560, the first and second cylinders are ranged side by side, connected to the main shaft, on a framed bed of cast iron. The air-pump and condenser are placed behind the second cylinder, and the pump is worked by a prolongation of the piston-rod of the cylinder through the back cover. Both the cylinders are steam-jacketed on the case, not at the ends. The valve-chest of the first cylinder is at the outer side, and steam is supplied to it from above through a slide stop-valve. The steam is exhausted from the first cylinder through a passage cast upon the jacket of the cylinder to the second cylinder; and thence it is exhausted through a passage over the jacket to the exhaust-pipe, which rises from the top of the cylinder and is carried horizontally to the upper part of the condenser. There it is condensed by a jet of cold water, and the mixture falls to the lower part, whence it is removed by the air-pump.

The main side girders of the bed-frame are 15 inches deep,
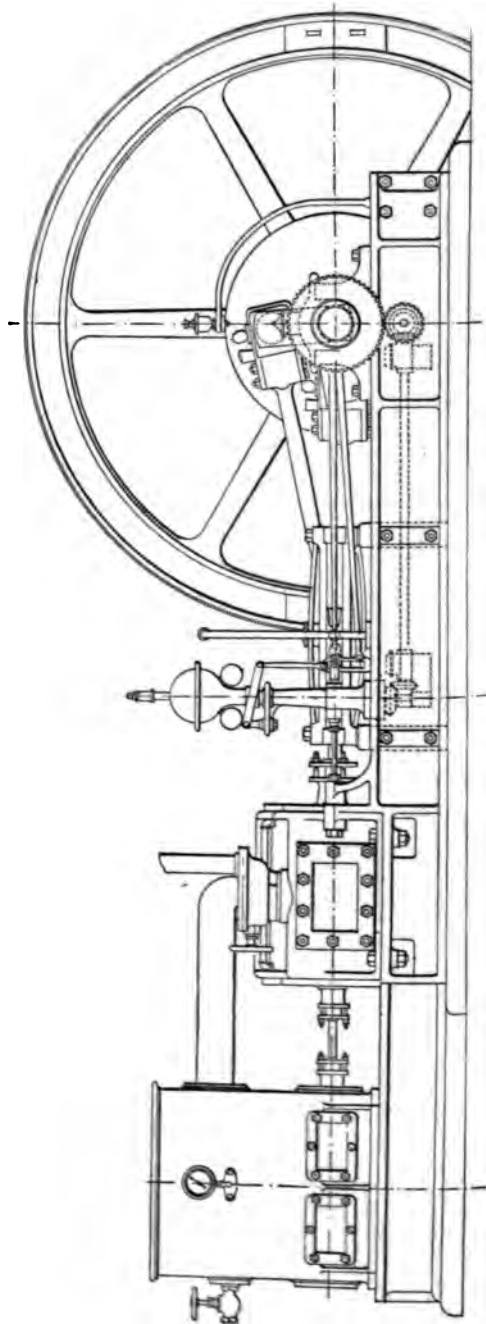
Fig. 559.—Davey, Paxman, & Co.: Horizontal Compound Condensing Steam Engine. Elevation. Scale 1/36th.

aving a vertical web 1 inch thick; lower flange 7½ inches wide, 1¾ inches
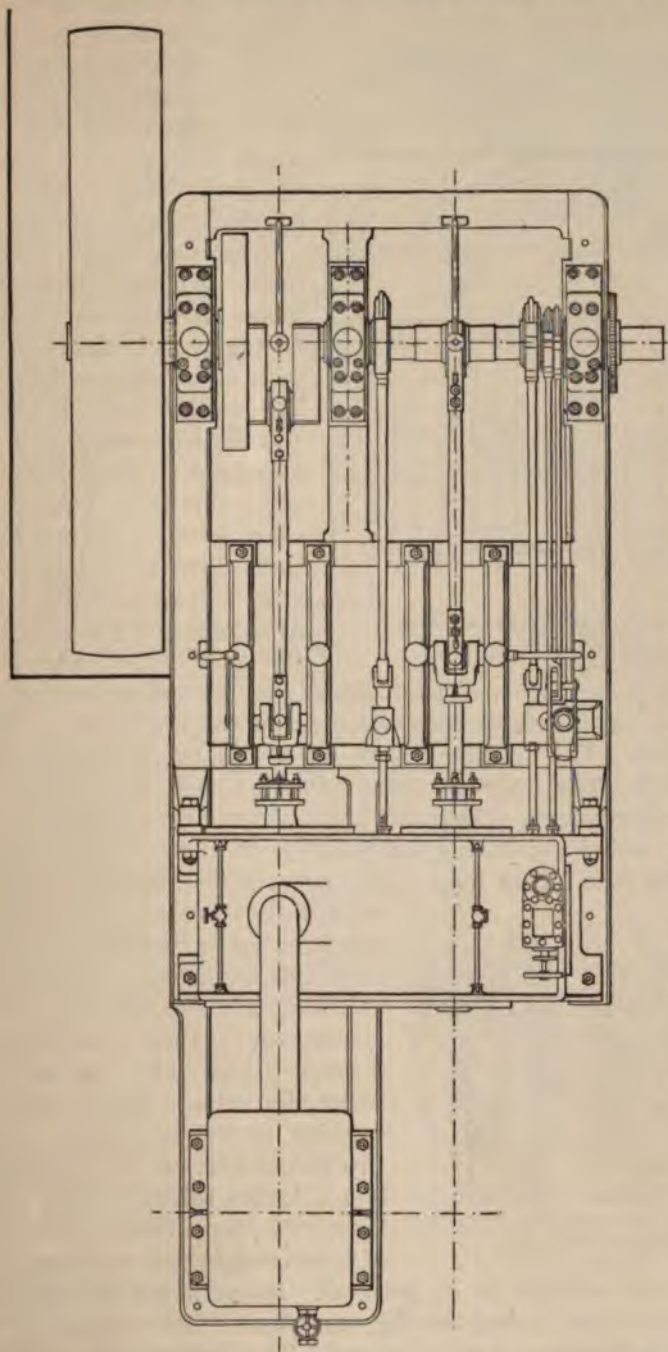
Fig. 560.—Davey, Paxman, & Co.: Horizontal Compound Condensing Steam Engine.   Plan.   Scale 1/36th.

hick at the edge;   upper flange 6½ inches wide, 1½ inches thick.

Recently, a box casting has been adopted for the portions of the frame
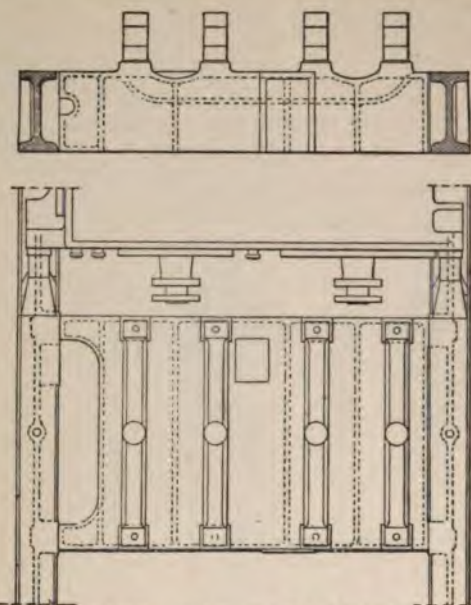
Figs. 561.—Davey, Paxman, & Co.: Box-framing.
Scale 1/36th.

under the guide-bars, shown in fig. 561, the ruling thickness being ⅞ inch. The side girders are firmly united by it. The girders under the condenser have a ⅝-inch web; upper flange 4⅝ inches wide, ⅞ inch thick; lower flanges 5½ inches wide, 1½ inches thick.

The cylinders, shown in section in figs. 563, are 13 inches and 22½ inches in diameter respectively, having areas in the ratio of 1 to 3, with equal strokes of 24 inches. The normal speed is 90 turns, or 360 feet of piston, per minute, with a pressure in the boiler of 120 lbs. per square inch. The regular indicator power is 150 horse-power, or three times the nominal power— 50 horse-power—which is reckoned at the rate of 8 square inches of the area of the second cylinder per nominal horse-power. The bodies of the first and second cylinders are ¾ inch and ⅞ inch thick respectively; and the liners are ⅝ inch and ¾ inch thick. The cylinder covers are 1⅜ inches thick, and the valve-chests 1 inch. The cylinders are constructed each with the usual three ports and slide-valves. The steam-ports of the first cylinder are 8 inches wide by 1 inch long, having an area $1/25$ of that of the piston. The exhaust-port is 2 inches long. The steam is distributed by a three-port
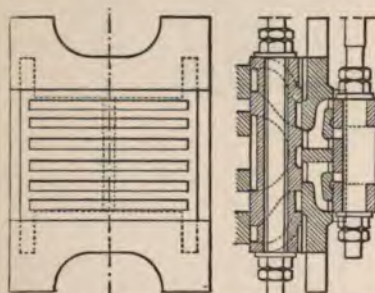
Figs. 562.—Davey, Paxman, & Co.: Valves of
First Cylinder.   Scale 1/10th.

main valve worked by a single fixed eccentric, and a variable double-ported cut-off or expansion-valve worked by a link-motion. (See figs. 562.) An intermediate or anchor plate, having two through double-ports, is stationary between the valves; the expansion-valve working on the back of it, guided by two ledges cast on it. The main valve is 2⅝ inches thick; it has 9/16 inch of lap outside, none inside; with 2¾ inches of travel, cutting off at 75 per cent, and opening to the exhaust at 95 per cent. Its ports are ⅞ inch long next the valve face, and 1 inch at the other face. It is worked by a 1-inch spindle, with double-nuts at each end. The anchor plate is 1⅝ inches thick; its ports, next the main valve, are 1 inch long; and the passages

are divided into four half-ports ½ inch long at the other face.   They have
7/16 inch of lap on the ports of the main valve, which is ⅛ inch less than
the lap of the main valve.   Consequently, the ports of the main valve
begin to be opened before those of the cylinder.   The expansion-valve is
a flat plate ⅝ inch thick, without lap; and it opens for steam through
the two half-ports of the anchor plate.   Its ports are 9/16 inch long.   It
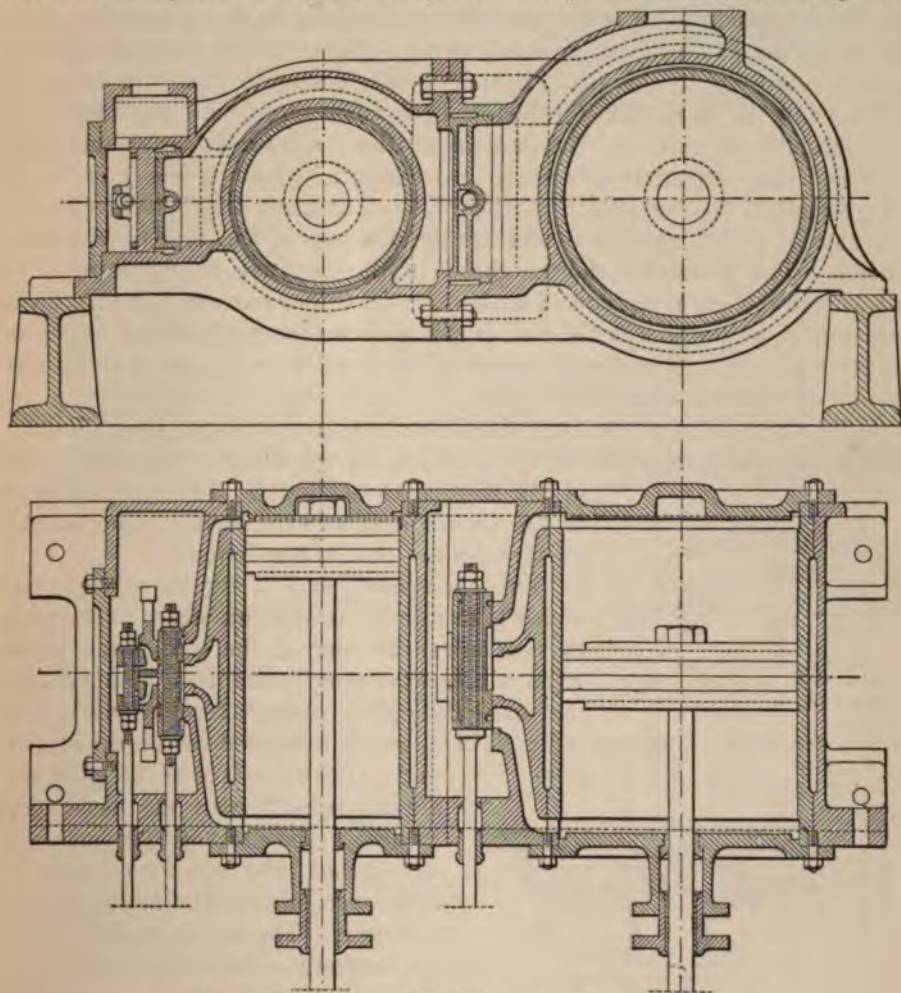
Figs. 563.—Davey, Paxman, & Co.'s Engine: Cylinders.   Scale 1/18th.

is worked by a 1⅛-inch spindle, fastened by double-nuts at each end.
It is not adjustable in itself; and the admission is varied by varying the
travel of the valve through a link-motion, consisting of the usual com-
bination of two eccentrics with a slotted link.   The travel is varied by the
action of the governor in raising or lowering the link.   The eccentrics
have different lengths of throw; the leading, or positive eccentric, as Mr.
Paxman calls it, having 1¼ inches of throw, giving 1¼ inches of travel to the

valve when in full gear; and the negative eccentric about one-half of that, or $9/16$ inch of throw. The link, which hangs vertically from the governor, is connected at the upper end to the positive eccentric, and at the lower end to the negative eccentric. The slot in the lever is straight, $7\frac{1}{2}$ inches long, and the eccentric rods are pinned to it at the back at a distance apart of $4\frac{1}{2}$ inches; and when the link is in its lowest position, the travel of the expansion-valve is equal to the throw of the leading eccentric. The throw of the eccentrics being so short as $1\frac{1}{4}$ inches and $9/16$ inch respectively, relatively to the distance apart of the eccentric pins, the obliquity of the link in its circuit of travel is necessarily slight, and the resistance by obliquity of stress to the control of the governor is correspondingly limited. The eccentric-rods are of great length—about 5 feet 3 inches— in proportion to the length of the link, a condition which is favourable for ease of action, since it moderates the obliquity of the link in its movements. The relatively shorter throw of the negative eccentric tends to neutralize the augmentation of lead which takes place in the ordinary link-motion, in proportion as the link is raised above the position for full gear with the valve. Steam may be cut off at from 0 to 75 per cent by the action of the expansion gear.

The valve-chest of the second cylinder is placed between the cylinders. The steam-ports are 2 inches by 14 inches, having an area equal to $1/14$th

Fig. 564.—Davey, Paxman, & Co.: Trick Valve of Second Cylinder. Scale 1/10th.

of the area of the cylinder. The exhaust port is $3\frac{1}{2}$ inches long and 14 inches wide, having an area $\frac{1}{8}$th of that of the cylinder.

The slide-valve is a Trick valve, fig. 564, which is so formed as to admit steam to the port by two entrances—one at the end of the valve when it opens the port, in the usual manner, and the other through a passage formed within the valve, from the other end of the valve, which is opened for steam at the end of the valve face of the cylinder, simultaneously with the usual entrance. The lap of the valve is $1\frac{3}{8}$ inches, and the travel, from a single eccentric on the main shaft, is 4 inches. The steam is cut off at 53 per cent. The spindle is of steel, $1\frac{1}{4}$ inches in diameter; connected to the valve by two pairs of nuts, brought up on a tubular distance-piece, leaving the valve free to leave the face of the cylinder under stress.

The valves are of cast iron, and the spindles are of steel.

Figs. 565.—Davey, Paxman, & Co.'s Engine: Steam-supply Valve. Scale 1/10th.

Steam is brought to the engine by a 3-inch pipe, fitted with a 3-inch steam-supply or regulator valve, figs. 565.

The casing is of cast iron, having a flat-face on which the valve, a gun-metal plate, is traversed by means of a 1-inch screw, having a left-hand square thread of $\frac{3}{8}$-inch pitch, turned by a hand-wheel and working in a nut secured on the back of the valve between two flanges. The port in the valve face is rhomboidal, $3\frac{1}{2}$ inches wide, with an oblique edge for the admission of steam, by the obliquity of which the opening is very gradually increased as the valve is shifted.

The steam is exhausted through a 6-inch pipe into the condenser,
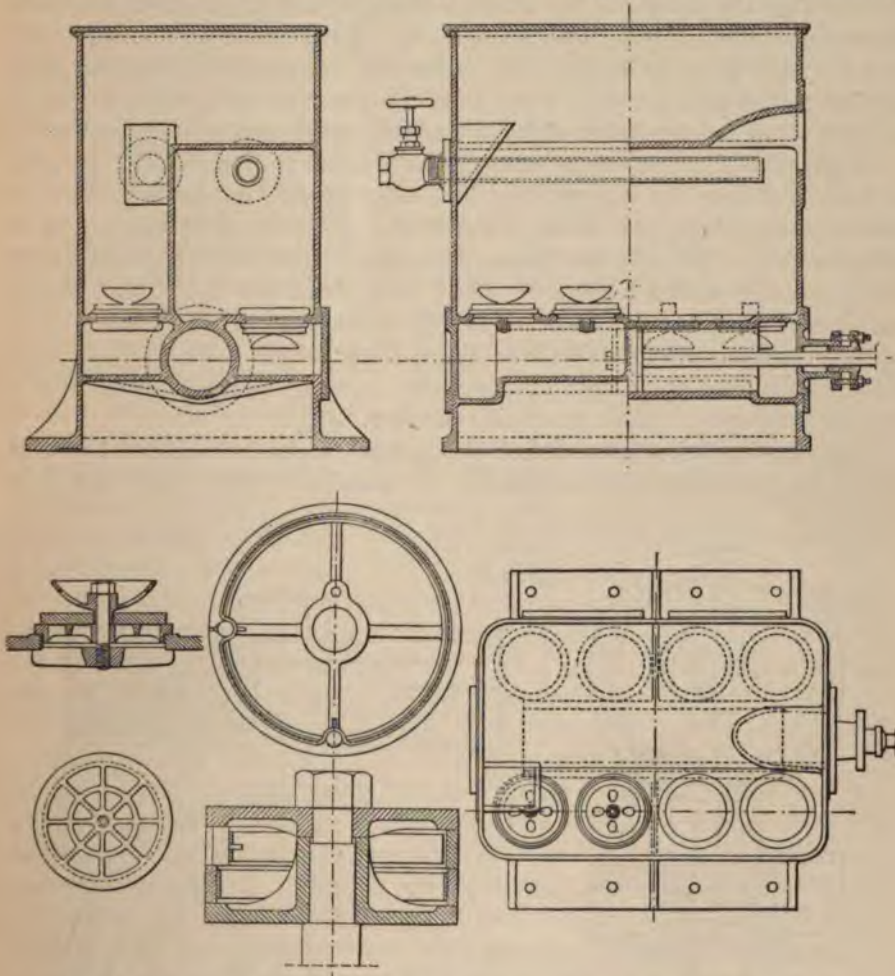
Figs. 566.—Davey, Paxman, & Co.'s Engine: Condenser, Air-pump, and Pump-piston. Scale 1/20th.

figs. 566. The condenser is a cubical cast-iron box, 3 feet long, 2 feet 1 inch wide, and 3 feet $7\frac{1}{4}$ inches high, outside measure, of $\frac{1}{2}$-inch metal, with a loose cover of the same thickness. The air-pump is double-acting, 6 inches in diameter, with a 24-inch stroke. It is lodged at the bottom of the condenser, the barrel forming one casting with it. The condenser

is divided by a horizontal partition about the level of the top of the barrel through valves in which, at one side of the pump, the water and vapour fall from the condensing chamber to the bottom; and at the other side are forced upwards into the hot-well. The condensing chamber is 14¼ inches wide and 17 inches high, and is partitioned off for the whole length of the box by ⅝-inch partitions, cast in one with the box and pump barrel. The exhaust steam is delivered through one end of the box into the condensing compartment, at the top. The injection-water is delivered at the other end by a 2-inch wrought-iron pipe, which traverses the chamber for nearly its whole length, and is perforated with small holes to deliver the water as spray. The water and vapour are discharged from the hot-well into a 3½-inch pipe, which is guarded by a baffle to maintain the water-level 2 inches above the crown of the condensing chamber.

There are four 6½-inch india-rubber valves, ⅝ inch thick, for the suction, and four for the delivery into the hot-well, on brass grid-seats, with cup-shaped guards. The piston of the air-pump is of brass, and is 3 inches thick. It is in two parts, of $5/_{16}$-inch metal, fastened together on the piston-rod with a nut on the end. The piston-rod is of steel, and is 1½ inches in diameter, reduced to 1⅛ inches within the piston. The packing consists of two cast-iron rings, each 1 inch wide and $5/_{16}$ inch thick, cut at one place and tightened by a wedge-piece acted on by a circular steel spring which fits inside the ring.

The bed-frame is constructed of pieces, easily separated and put together again, for convenience of shipment. It consists of two main cast-iron
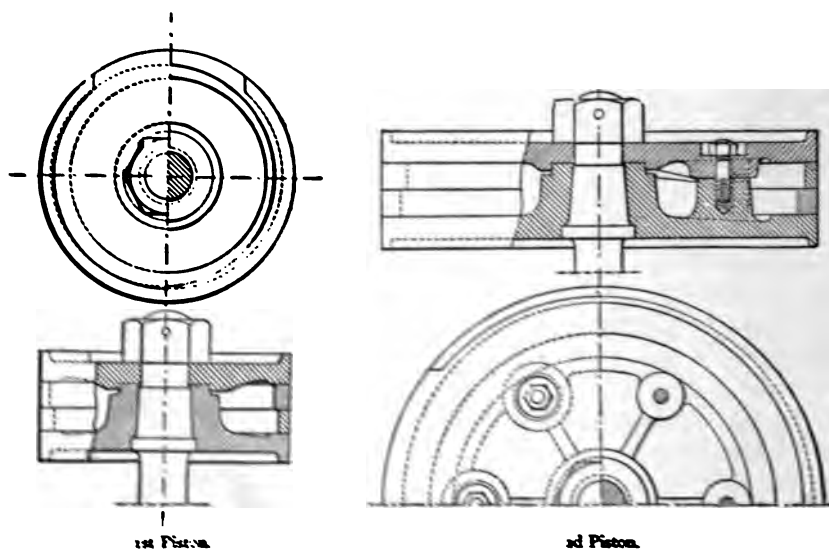
1st Piston.   2d Piston.
Figs. 562.—Davey, Paxman, & Co.'s Engine: Pistons. Scale 1 10th.

double-flanged girders, bound with cross-girders—planed and faced at the ends. The main girders are shown in section, under the cylinders, in fig. 563; 12 inches deep, 7½ inches wide at the base, and 6½ inches wide at the

top.   From the cylinders to the main-shaft end the girders are 2 inches higher, being 14 inches deep.   The two girders are tied by a cross-girder at the main-shaft end, and by the cylinders at the other end, and by two narrower cross-girders, by which also the guide-bars are supported.   The condenser is carried by an outlying piece of framing, bolted to the main framing.   The cylinders are formed with side brackets, by which they are bolted at the bottom and the front to the frame and thereby strongly secured.

The pistons, figs. 567, are of cast iron, each in two pieces,—the body and the junk-ring.   The first piston is 13 inches in diameter and $5\frac{1}{2}$ inches thick, and it holds two packing rings of cast iron, each $1\frac{1}{4}$ inches wide, of which the inner face is eccentric with the outer face, the thickness varying from $15/16$ inch to $9/16$ inch.   The piston-rod is of steel, $2\frac{1}{2}$ inches in diameter, let into the piston with a collar, and tapered, and fastened with a nut on the end, by which also the junk-ring is held.   The nut is secured by a through-pin.   The second piston is 6 inches thick, with two packing rings of cast iron, each $1\frac{3}{8}$ inches wide.   The piston-rod is $2\frac{1}{2}$ inches in diameter, and is fastened similarly to the first piston-rod.   The junk-ring is also fastened to the body of the piston by six $\frac{3}{4}$-inch screw-bolts.

The crossheads, figs. 568, are of wrought iron, forked, 4 inches wide between the forks.   Each holds a steel gudgeon $2\frac{3}{4}$ inches in diameter, secured by a through-pin; the gudgeon being extended to take the slide-blocks, which are of cast iron 10 inches long, $3\frac{1}{2}$ inches wide.   The rod is fixed in the crosshead, in which it is slightly tapered, from $2\frac{1}{2}$ inches to $2\frac{1}{8}$ inches in $5\frac{1}{4}$ inches of length of socket, by a steel cotter $9/16$

Figs. 568.—Davey, Paxman, & Co.'s Engine: Crosshead and Slides.
Scale 1/10th.

inch thick and $2^3/_{16}$ inches wide, having $1/16$ inch of taper.

The connecting-rods, figs. 569, are of wrought iron, 5 feet in length, or five times the length of the cranks.   They are $2\frac{1}{2}$ inches in diameter at the crosshead end, $2\frac{3}{4}$ inches at the crank end, and swelled to $3\frac{1}{8}$ inches at the middle.   They are constructed with butts and straps, and square brasses.   The straps are fastened with two steel bolts and nuts, and the brasses are adjustable by means of a steel cotter with double-nuts.   The continuous lubrication of the crank-pins is effected by suspending an oil-cup above each crank-pin, from which a wick depends.   The wick is touched by and it parts with oil to a small receptacle on the strap of the connecting-rod, once in every revolution.

The main shaft, figs. 570, is of steel, 6 inches in diameter, having two double-limb cranks, in three bearings, of which two are on the side framing

and one is between the cranks.   The two outer journals are 6 inches in diameter and 9 inches long.   The crank-pins are 6 inches in diameter and
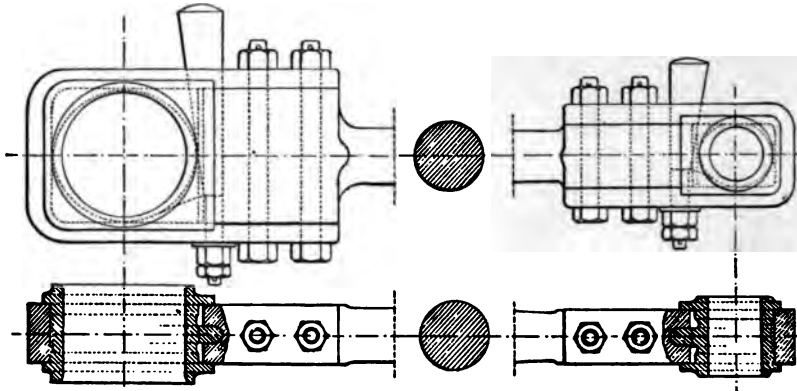
Figs. 569.—Davey, Paxman, & Co.'s Engine: Connecting-rod.   Scale 1/10th.

5 inches long; the limbs of the cranks are 5 inches by 7 inches in section. A balance-disc of cast iron is applied to the shaft, close to and sunk about 1½ inches upon the outer limb of one of the cranks, as in figs. 570. It is hollow at one part and solid at the opposite side, and is so designed
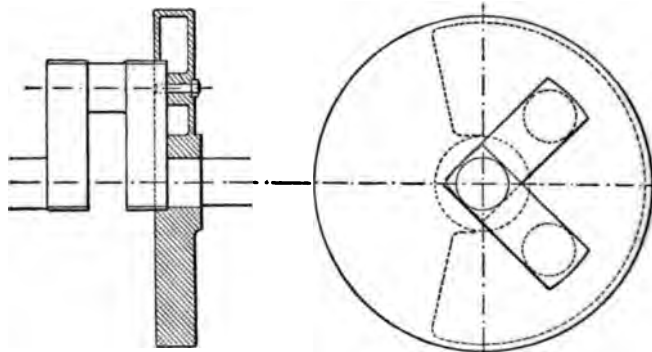
Figs. 570.—Davey, Paxman, & Co.'s Engine: Crank-shaft and Balance-disc.   Scale 1/24th.

as to statically balance the two cranks.   It is bored out to fit the shaft, and is exactly fitted to the crank-arm or limb, and secured to it by a screw-bolt.   The disc is turned at the rim and is bound by a band of wrought iron shrunk on, as a security against its rupturing or flying to pieces.

The pedestals for the main shaft, figs. 571, are 30 inches long at the base by 7 inches wide, and they stand 6½ inches high to the centre. They have a 6-inch bore, 9 inches long, and are made with means of lateral adjustment for wear.   The brasses are in three pieces, a bottom piece and two side pieces, of which the latter take each one-half of the top.   The partings of the sides from the bottom are horizontal, admitting of a sliding adjustment; and the parting at the top is fitted with an adjusting liner. The pieces are brought together by means of two wedges or cotters at one

side of the bearing, screwed at the upper ends. and secured in place by
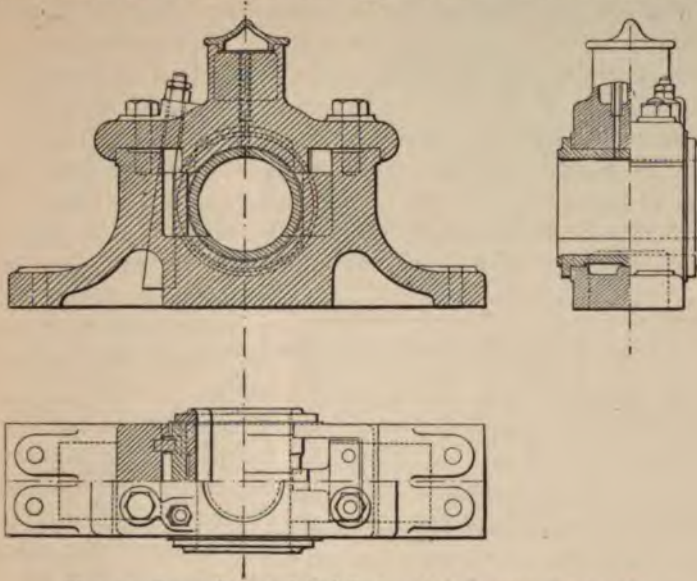
Figs. 571.—Davey, Paxman, & Co.'s Engine: Main Pedestal.   Scale 1/12th.

double-nuts. Lubrication in duplicate, by capillary action, is provided for by dividing the oil-cup on the cover of the pedestal into two by a vertical partition; one half holding oil, the other half holding fat or grease, which melts on the slightest rise of temperature and flows immediately.

The fly-wheel is of cast iron, 10 feet in diameter, 18 inches wide at the rim. It is in halves, keyed and bolted together; fixed on the end of the main shaft, overhung.

The governor, fig. 572, is of the class of loaded or dead-weight governors. The arms are not straight, but bent, and are lodged for the most part within a spherical dead-weight, where they are pinned in the centre-line of the spindle.   The upper part of each arm is slotted to receive a friction-roller, which rolls in the slot as the arm rises or falls for varying speed.   The roller is pivoted to the dead-weight, and with it the dead-weight rises and falls.

Fig. 572.—Davey, Paxman, & Co.'s Engine: Governor. Scale 1/6th.

The rollers move, of course, in

vertical lines, parallel to the axis; and the horizontal distance of the roller-pivots, on which the dead-weight is suspended, from the fulcrum of the levers—otherwise, the leverage and resistance of the dead-weight—is uniform for all elevations of the revolving balls, instead of increasing with the speed and the rise of the balls, as in ordinary loaded governors. For this reason a superior degree of sensitiveness and efficiency is claimed for the governor. A helical steel spring is applied above the dead-weight, to co-operate in regulating the rise of that weight and the play of the balls. The speed may be regulated by varying the tension on the spring, which is adjusted by means of a finial nut and screw at the upper end. The governor is driven by gearing from the main shaft, and makes $2\frac{1}{4}$ revolutions for one of the engine.

Figs. 573.—Davey, Paxman, & Co.'s Engine: Indicator Diagrams.

Engines of the class above described have been at work at the recent International Exhibitions at South Kensington, in the electric-light department. On one occasion the driving band on one of the engines suddenly broke, but the motion was effectively controlled by the governor with a scarcely perceptible increase of speed.

Samples of indicator diagrams from this engine are given in figs. 573, usually indicating 150 horse-power. The average consumption of steam per indicator horse-power, per hour, is estimated as $22\frac{1}{2}$ pounds; and that of best Welsh coal as 2.20 pounds.

According to more recent practice, the first cylinder is 14 inches in diameter, instead of 13 inches. making cylinder-ratio 2.6. The pistons, figs. 574, are now packed with two cast-iron rings of uniform thickness, side by side, each cut at an angle with a very thin saw. They are pressed outwards by a steel ring, turned to fit inside them. The ring is drawn together to cause elastic action, before being turned; and it is bored eccentrically.
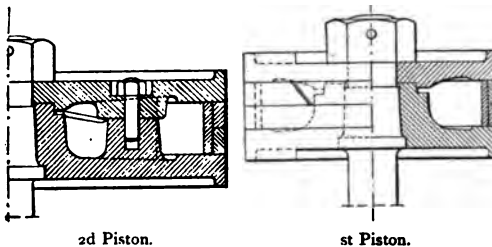
2d Piston.   st Piston.

Figs. 574.—Davey, Paxman, & Co.: Recent Pistons.
Scale 1/10th.

In recent engines, condensing, 21 pounds of steam are consumed per indicator horse-power per hour; non-condensing, 24 pounds.

The weight of the earlier engine is 10 tons $17\frac{1}{2}$ cwts. including the weight of the fly-wheel, 3 tons $3\frac{1}{2}$ cwts. The bed-frame weighs 1 ton

13 cwts., the main shaft 14 cwts., and the condenser 1 ton 7 cwts. The price of the engine complete was £765, or £70, 7s. per ton of weight.

The price of the more recent engine complete with condenser is £818, 10s., or £58, 10s. per ton of weight. The weight is 14 tons.

CHAPTER XX.—TANDEM COMPOUND CONDENSING STEAM ENGINE OF 30 HORSE-POWER.

CONSTRUCTED BY MESSRS. HOLBOROW & CO., DUDBRIDGE.

(Cylinders 13 inches and 24 inches diameter, 24 inches stroke.)

This engine, figs. 575 and 576, is compactly designed, with the cylinders in tandem. The condenser and air-pump are placed on the same level as the cylinders, facing the crank-disc, the air-pump being worked directly off the piston-rod. The two cylinders are placed on one cast-iron bed; and the main pedestal and condenser are placed together on another cast-iron bed. The first cylinder and the main pedestal are, in addition, directly connected by a cast-iron box frame, with which the pedestal is in one piece; but the stress of the second cylinder is transmitted partly through its bed, and partly through a tie-bolt by which it is connected to the first cylinder at the upper part.

The cylinders are respectively 13 inches and 24 inches in diameter, with a stroke of 24 inches; steam-jacketed round the cases only. The areas of the cylinders are as 1 to 3.40. The ordinary speed is from 300 feet to 350 feet, or from 75 to 87 turns, per minute, with working pressures in the boiler of from 60 lbs. to 80 lbs. per square inch.

A direct clearance of ¼ inch is provided at each end of the cylinders. Each cylinder is cast solid with the jacket. The barrels are 1¼ inches thick, and the jackets are ¾ inch thick. The first cylinder is cast in one with the front cover and the valve-chest. In the second cylinder, both covers are separate; and the front cover is placed from within the cylinder, in order that the first piston and cylinder cover may be withdrawn through the second cylinder, and so easily removed for repair. The covers and valve-chests are ⅞ inch thick; except the front cover of the first cylinder, 1¼ inches thick, which takes the stress of the frame. The cylinders are made with brackets, by which they are bolted to the bed. The bed is of ⅞-inch metal, and stands 4 inches high;—it is 2 feet 4 inches wide and 7 feet 8 inches long. Though shallow in appearance, the bed has proved to be of sufficient strength. It is bolted down with six 1½-inch bolts. The centre-line of the cylinders is 19½ inches above the level of the foundation.

The cylinders are fitted with ordinary slide-valves, working on three-ported valve-faces. For the first cylinder the steam-ports are 1¼ inches long by 8 inches; and the exhaust-port is 2½ inches long. The areas are

respectively $1/_{13.3}$ part and $1/6.7$ part of the piston-area. The main valve is 13½ inches long, 3 inches thick; and the lap is 1¼ inches, the lead ⅛ inch, and the travel 5 inches. A Meyer expansion-valve works on the back of the main valve, with right-hand and left-hand screws in gun-metal nuts, of $7/_{16}$-inch pitch, adjustable by hand. For the second cylinder, the steam-ports are 1½ inches long by 13 inches, and the exhaust-port is 3 inches long, having areas respectively about $1/_{23}$d part and $1/_{11.6}$ part of the piston-area. The lap of the valve is 1 inch, the lead ⅜ inch, and the travel 5 inches. The valve-spindles are of stee 1¼ inches in diameter. The main valves are loosely traversed by the spindles, and are held in place by double nuts on the spindle at each end of the valve. The spindles of both valves of the first cylinder pass through stuffing-boxes at each end of the valve-chest. At the front end they are guided in a fixed guide-block outside, in which the main spindle is enlarged to 2½ inches in diameter. At the back, the main-valve spindle is coupled to the valve-spindle of the second cylinder, and the ex-pansion-valve spindle is fitted with a hand-wheel for adjustment to vary the cut-off. Steam is, as a rule, cut off at half-stroke in the first cylinder; and at from five-eighths to three-fourths of the stroke in the second cylinder.

The valve-chests are brought up flush with the front ends of the cylinders; and in consequence the ports are nearer to the front than to the back. By this dis-
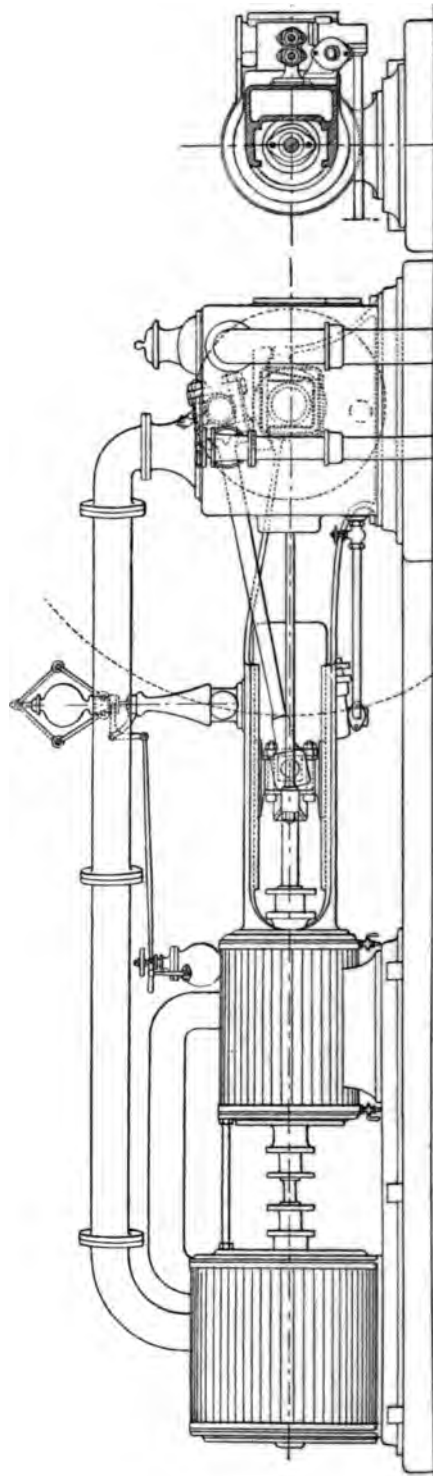
Fig. 575.—Holborow & Co.: Tandem Compound Condensing Steam Engine. Elevation and Cross Section.   Scale 1/32d.
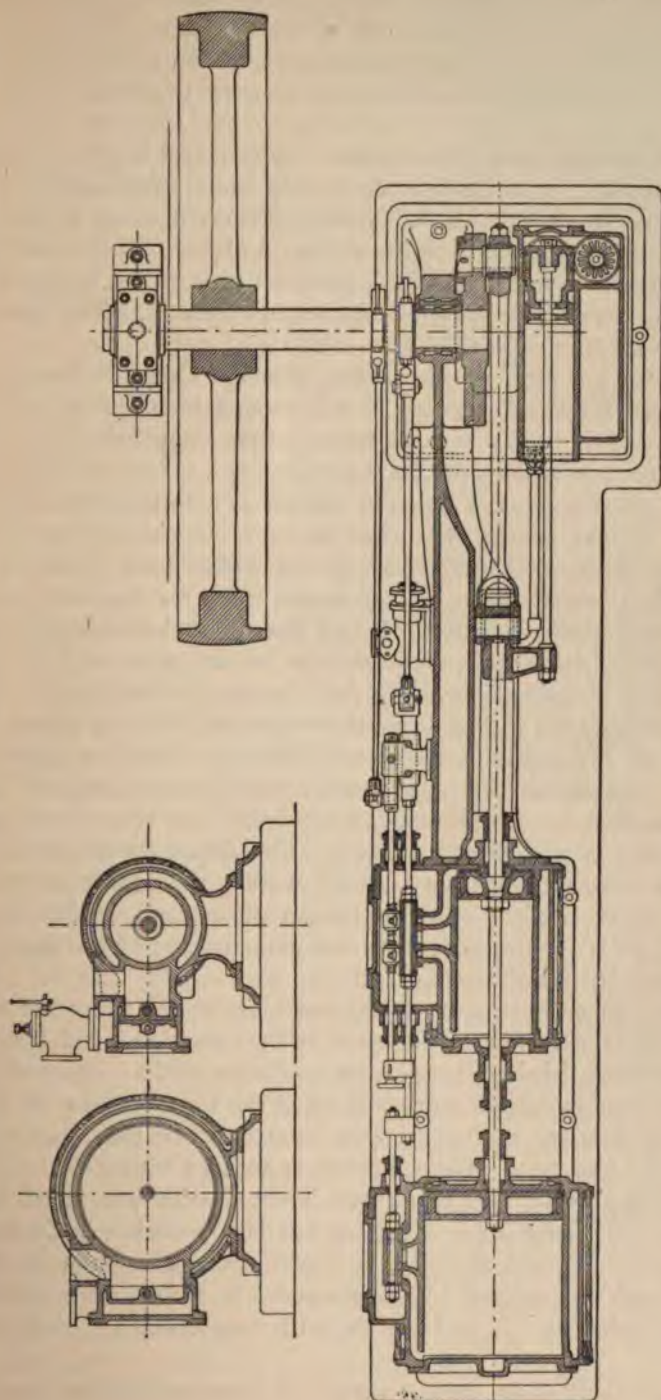
Figs. 576.—Holborow's Tandem Compound Engine.   Sectional Views.   Scale 1/32d.

position, the patterns of the cylinders are adapted for different lengths of stroke with little alteration, there being only the length of one port to alter, and one end of the body of the cylinder. The fixing of lagging also is simplified; and the valve-spindles, of course, are shorter by the advance of the valve-chests and ports towards the front ends of the cylinders.

Steam is brought to the first cylinder by a 3½-inch pipe (3 inches for moderate lengths), fitted with a steam-stop and throttle-valve in one—equilibrium double-seated. It is exhausted from the first to the second cylinder through a 4½-inch cast-iron pipe; and from the second cylinder to the condenser through a 5½-inch cast-iron pipe. The injection-pipe is 3 inches, and the overflow-pipe is 5 inches in diameter. The pipes are, in each case, about ⅜ inch in thickness.

The pistons are each in one casting, 5 inches thick; hollow, of 1-inch metal; grooved for a packing-ring of cast iron 3 inches wide and ⅝ inch thick. The ring is turned to a diameter larger than that of the cylinder, cut at one place, notched and lapped to make a joint, then sprung into place. The piston-rod is of steel, in one piece, extending from the cross-head to the second piston, 2¾ inches in diameter, reduced to 2¼ inches between the pistons. The rod is tapered within each piston, which is fastened with a nut at the back, 1¾ inches thick for the first piston, and 1½ inches for the second piston. It is 8 feet 7½ inches in length.

The crosshead is of malleable cast iron, in one piece, with the bracket from which the air-pump is worked cast on one side of the socket. The socket is bored out 6½ inches deep, to take the end of the piston-rod, round which there is 1½ inches of metal, and which is turned to a diameter of 2½ inches. Gun-metal bearings for the connecting-rod gudgeon are fitted with a square seat into the crosshead, to which they are secured by a cap and four 1-inch turned bolts and nuts. The slides, above and below the crosshead, are of cast iron; they are 13 inches in length and 5½ inches wide, bored to receive the studs on the crosshead, and secured to it with pins. The guides for the slides are cast with the bed of the engine; they are ledged to keep the slides in place.

The connecting-rod is of steel, 5¼ feet long, or 5¼ times the length of the crank. It is 3 inches in diameter at the crank-end, and for half the length of the body, whence it tapers to 2⅜ inches at the crosshead-end. It is forked at the crosshead-end, and fitted with a steel pin or gudgeon, 3¼ inches in diameter, and 4½ inches long between the forks, which are shrunk on the gudgeon. The gudgeon is secured with keys. The forks are 1½ inches thick. The crank-end is fitted with gun-metal bearings, and cap-and-bolt fastenings. The bearing is 4⅛ inches in diameter and 4½ inches long; ¾ inch thick at the centre-line. The palm on the connecting-rod and the cap are 1½ inches and 1⅜ inches thick respectively, and are 9¾ inches by 3⅜ inches wide, with two turned 1¾-inch bolts and nuts.

The main shaft is of steel, 7 inches in diameter, having two journals

6 inches in diameter and 8 inches long. The crank or crank-disc is of cast iron, 33 inches in diameter, 3½ inches wide at the rim, 4½ inches deep at the centre; counterweighted to balance the crank-pin and the end of the connecting-rod. The nave is 4½ inches thick, 12 inches in diameter, shrunk on to the shaft, and secured with a key 1¾ inches by 1 inch. The crank-pin is of steel, and is 4 inches in diameter, slightly taper, and 4½ inches long at the journal. It is formed with a collar, and is driven tightly into the crank-disc, which is shrunk upon it. The eye in the disc is 5 inches deep, in which the pin is secured with a cotter, ½ inch by 1¼ inches, and with a wrought-iron hoop, 1 inch by 1½ inches in section, shrunk on over the eye, at the back. The fly-wheel is of cast iron, 9 feet in diameter, and 15 inches wide at the rim, which is turned slightly round on the face, for driving by a belt. The nave is 15 inches in diameter, 11 inches wide. There are six arms of oval section, 5¾ inches by 3½ inches at the nave; 5 inches by 3 inches at the rim. The wheel is fixed on the shaft with one key, 1¾ inches by 1 inch.

The frame is a box-girder casting, with which the main pedestal, slide-guides, and the flange to join to the cylinder are cast in one piece. The box portion is 6 inches wide, 15½ inches deep, of ⅞-inch metal. The cylinder-flange of the frame is 1¼ inches thick. It is extended laterally to join also to the valve-chest. Over the guides the frame measures 14 inches wide; the guides are of 1¾-inch metal. Near the pedestal the box form vanishes, and is succeeded by a single web, with top and bottom flange, 1½ inches thick. The pedestals have 6-inch bearings, 8 inches long for the main pedestal, and 9 inches for the outer pedestal, to which the fly-wheel is in proximity. The bushes of the main pedestal are of ½-inch metal, and those of the main pedestal are in two pieces parted diagonally at 45°, to take up wear horizontally and vertically. But the parting lines are vertical, and adjustment is effected by means of a wedge inserted vertically between the side of the pedestal and the bearing. The cap is fastened with four bolts and nuts. The outer pedestal is of an ordinary form. Each pedestal is bolted down with two 1½-inch bolts.

There are two eccentrics of cast iron, with cast-iron straps, for driving the valves—one for the main valves of the first and the second cylinders, and the other for the expansion-valve, of 5 inches and 3 inches throw respectively. They are 3 inches and 2¼ inches wide respectively. The eccentric-rods are of wrought iron. The small ends are eyes cottered to the rods, bushed with gun-metal; adjustable with a key. The main valve-spindle is forked to receive the eye, which is joined to it with a 1½-inch pin, 2¼ inches between the forks. The expansion-valve spindle is fitted with a long sleeve, by which it is carried in the fixed guide; and that it may be free to rotate when the hand-wheel is turned for adjustment, it is jointed to the eccentric-rod by means of a short sleeve carrying a 1¼-inch pin, on which the eye of the eccentric-rod end works.

The condenser is a casting of ¾-inch metal, 3 feet long, 18 inches wide, and 2 feet 7 inches high outside; in one casting with the air-pump, which

is single - acting, and is worked horizontally from the crosshead. The exhaust steam is delivered through the top of the condenser, when it meets the condensing water supplied through a 3-inch cast-iron pipe at the front, fitted with an injection-cock and a water-spreader inside. The water and vapour fall to the bottom, round the barrel of the pump, whence they are lifted by suction through two lower valves into a small compartment of the condenser. Thence they are forced through two upper valves into the hot-well, whence they flow off by a 5-inch cast-iron waste-pipe of ½-inch metal. The valves are india-rubber discs 7½ inches in diameter, ⅝ inch thick, on gun-metal seats 6½ inches in diameter of openings, with check-discs to limit their lift. The air-pump is of 1-inch metal, and is bored to 8½ inches in diameter. The ram is turned to fit the barrel, with three water-grooves to prevent leakage, and a stuffing-box packed with hemp loosely plaited, and saturated with Russian tallow. It is worked direct from the crosshead by a 1½-inch rod fixed by a nut to the bottom of it.

A Porter governor is employed to regulate the speed. By a simple connection it controls the throttle-valve. It is driven by a band—occasionally by two bands for safety—and the speed is about 350 turns per minute.

The feed-pump is of cast iron, single-acting, with a gun-metal ram 2¾ inches in diameter, having a stroke of 5 inches. It is capable of delivering from two to three times the maximum quantity of feed-water required. It is bolted to the frame, and is worked by a rod from the main eccentric, with a stroke of 5 inches. There are two three-leaved valves for suction and delivery, 1⅞ inches in diameter. The feed-water is taken by a wrought-iron pipe from the bottom of the condenser, having a stop-valve to regulate the supply.

The weight of the engine is from 10 tons to 11 tons, comprising from 3½ to 4 tons, the weight of the fly-wheel; 13 cwts., the weight of the base-plates; and 18 cwts., the weight of the girder-frame. The price is £365, or from £33 to £36, 10s. per ton of weight. There are eight holding-down 1¼-inch bolts. The working-pressure in the boiler is 60 lbs. per square inch; and the regular speed is 300 feet of piston, or 75 turns, per minute. The steam is cut off at half-stroke in the first cylinder, and exhausted at about 90 per cent. In the second cylinder it is cut off at from ⅝ths to ¾ths of the stroke, and exhausted at 90 per cent into the condenser. The regular indicator power is three times the nominal power, or 90 indicator horse-power. The nominal power is reckoned at from 18 to 19 circular inches of the second cylinder per horse-power.

The foundation is of brickwork or large stones, as may be had most conveniently in the neighbourhood, well set together in mortar, with a bed of large stones on the top, at least 3 inches thick, bracketed together with iron clamps fastened with lead. A bottom bed of concrete 5 inches thick is laid. The foundation is 14 feet long at the top, 3 feet 5 inches wide, 4 feet 4 inches deep to the concrete.

CHAPTER XXI.—HORIZONTAL COMPOUND CONDENSING STEAM ENGINE OF 10 HORSE-POWER.

CONSTRUCTED BY MESSRS. J. WARNER & SONS, LONDON.

(Cylinders 6 inches and 10 inches diameter, 12 inches stroke.)

This engine, figs. 577 and 578, is specially designed to combine uniformity of speed with economy of steam. It is fitted with automatic expansion-gear, on Rackham's system, by means of which the speed is regulated by the action of the governor, by varying the cut-off without reducing the initial pressure in the cylinder by throttling. There are two cylinders, tandem or in line, on one base plate, with the air-pump. The condenser is bolted to one side of the air-pump.

The bed or base plate is of cast iron, in one piece, flat at the top, except where it is depressed, in order to clear the second-cylinder covers, as well as to drain off water by leakage from the glands, which is led off by a pipe to the drain. The bed is made with sides and ends, standing $4\frac{1}{2}$ inches high. It is of $\frac{3}{4}$-inch metal. The centre-line of the cylinders is 8 inches above the level of the top of the bed. The bed is bolted down to the foundation with eleven 1-inch bolts. The foundation is $3\frac{1}{2}$ feet deep.

The first cylinder, figs. 579 and 580, is 6 inches in diameter, and the second is 10 inches, with a stroke of 12 inches. The capacities are as 1 to 2.80, making the nominal expansion-ratio 5.60, when steam is cut off at half-stroke of the first cylinder. The engine is designed to work with a pressure of 70 lbs. per square inch in the boiler, at a speed of 150 turns, or 300 feet of piston, per minute. The estimated indicator power, working with sixfold expansion, is 25 horse-power. The ratio, 3.25, of the cylinders is generally preferred. In this case the ratio 2.80 was adopted for the sake of economy of construction. The nominal power is reckoned at the rate of about 10 circular inches of area of second cylinder, at speeds of piston of about 300 feet per minute. The factor of safety used in the design of the engines is 10.

The cylinders are steam-jacketed round the barrels. The barrels are cast separately from the jackets, and these are in one piece with the valve-chests. The barrel and jacket are equal in length, and flush at the ends. They are inclosed at each end by the cover, which is bolted to the jacket. The cylinders are of $\frac{1}{2}$-inch metal; and they are ribbed on the outside, having two intermediate circular ribs, in addition to the end flanges, and four longitudinal ribs. These ribs are $\frac{3}{4}$ inch thick, and they project $\frac{5}{8}$ inch, and of course strengthen the barrel, while they add in some degree to the heat-conducting surface from the jacket-steam into the cylinder.

The distribution of the steam is effected by slide-valves, one to each cylinder, on one rod, in two parts screwed together, and worked by the same eccentric; and by a separate expansion-valve for the first cylinder, worked by a separate eccentric, by which the cut-off may be varied. See
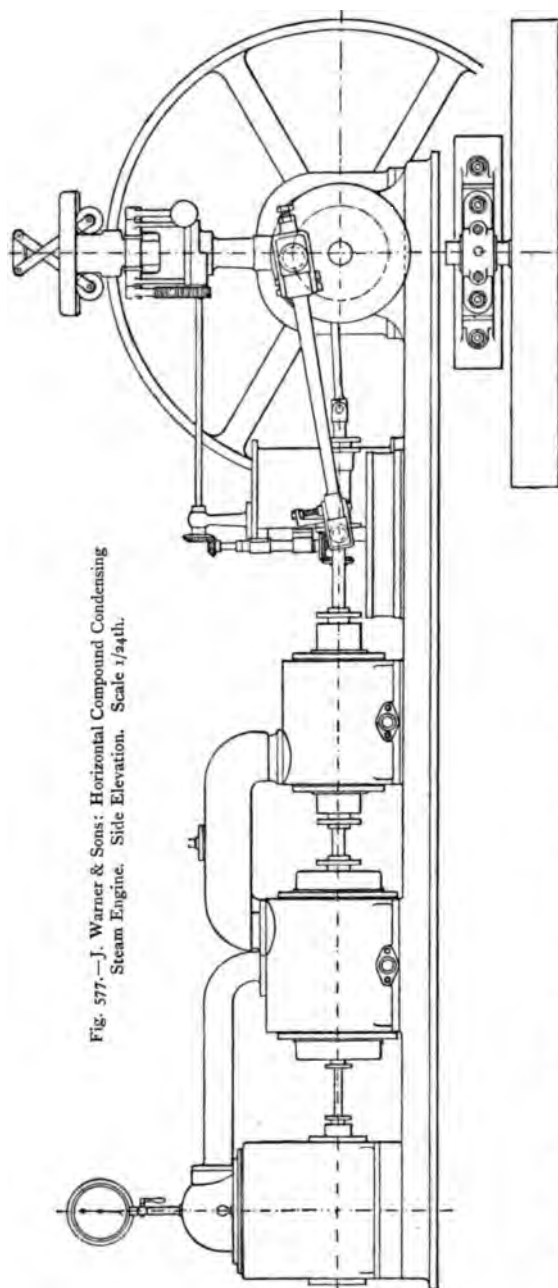
Fig. 577.—J. Warner & Sons: Horizontal Compound Condensing Steam Engine. Side Elevation. Scale 1/24th.

Fig. 578.—J. Warner & Sons: Horizontal Compound Condensing Steam Engine. Plan. Scale 1/24th.
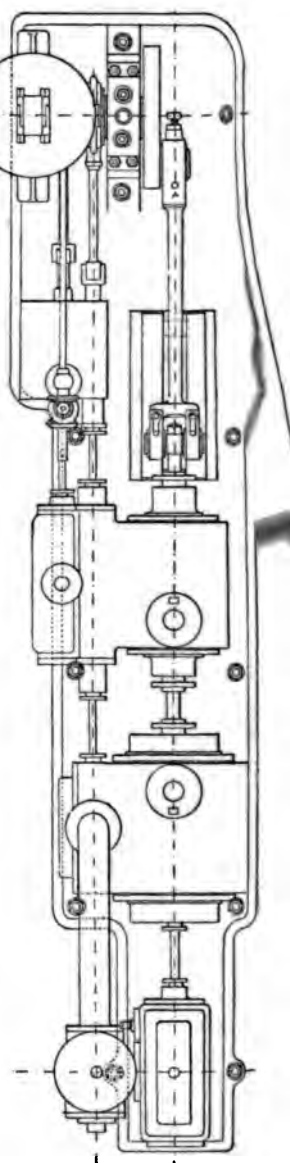
figs. 581. The travel of each valve is 2½ inches. The first cylinder has four ports, two at each end, for steam and for exhaust.

The periods of admission in the two cylinders are as follows:—

First cylinder, front end,................................... 78½ per cent.
     „   „   back   „   81   „
Second „   front   „   75   „
     „   „   back   „   .... 76½   „

The expansion-valve cuts off at from zero to 85 per cent of the stroke. The expansion-eccentric is set diametrically opposite to the crank-pin.
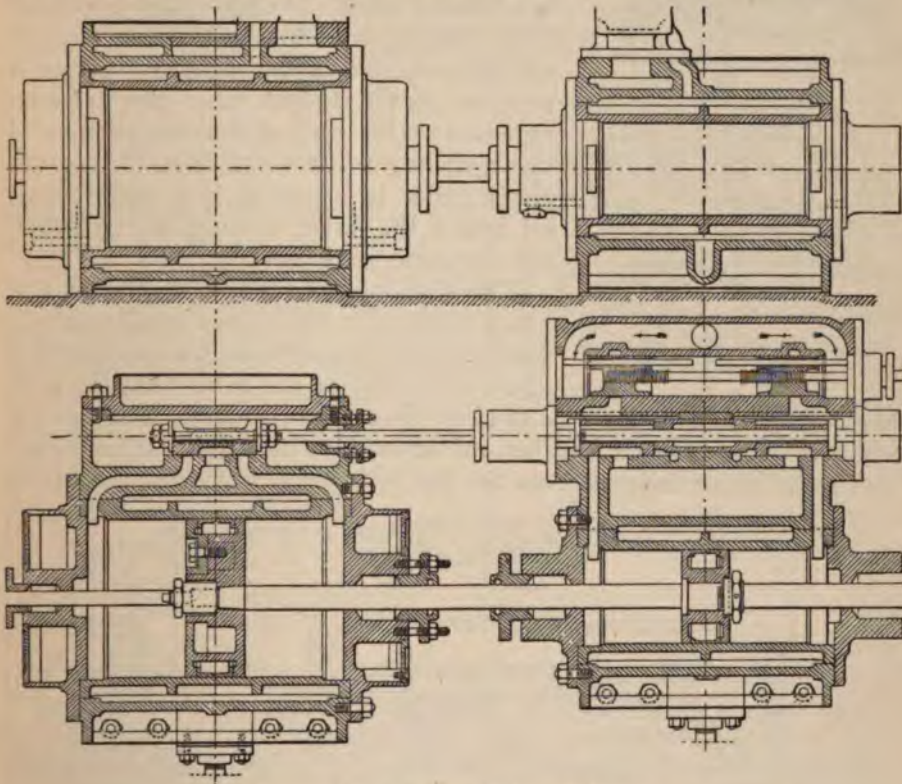
Figs. 579.—Warner & Sons: Cylinders. Scale 1/12th.

The half-valves for expansion are kept apart on the spindle by an intermediate packing-block, and held by a collar and collar-nut on the end of the spindle. This nut is of considerable thickness—2 inches—and it unites the two parts of the spindle, end to end; that is to say, the valve-spindle of the first cylinder and that of the second; and the union is made within the valve-chest of the first cylinder. The way through the valves is larger than the spindle; and the nut is screwed up so as to leave the valves free to move to or from the valve-faces, and is locked by the jamming of the valve-spindles on each other. The expansion-valve works in a cylindrical

chamber over the main valve. The valve itself is cylindrical, as a piston-valve, in two parts, one for each end of the cylinder, on right-hand and left-hand screws cut on a spindle, for the adjustment of the valve for various admissions, in the manner of the Meyer valve. The valve is 2½ inches in diameter, and each piece is 4 inches long. The spindle is of steel, ⅝ inch in diameter, and the screws are ⅞ inch, and are cut with four square threads of 1-inch pitch,—such that by one revolution of the screw the valves would each be shifted 1 inch. The valves are prevented from rotating by two steady pins, screwed one into each end of the chamber. Steam is supplied from a 1⅝-inch steam-pipe to a passage cast on the back of the expansion-valve chest, leading to each end of it, whence the steam passes by a port ¾ inch long, formed all round the valve, through the partition into the main valve-chest.

Figs. 580.—Cylinders: Cross Sections. Scale 1/16th.

The slide-valve of the second cylinder, figs. 581, is traversed by the ¾-inch spindle, already noticed, which passes through a 1⅛-inch hole cast in the back of the valve, allowing freedom for the valve to leave or to close upon the valve-face. The valve is held between a collar-nut and jam-nut screwed on the spindle at each end.

The steam is exhausted from the first cylinder by a passage ¾ inch by
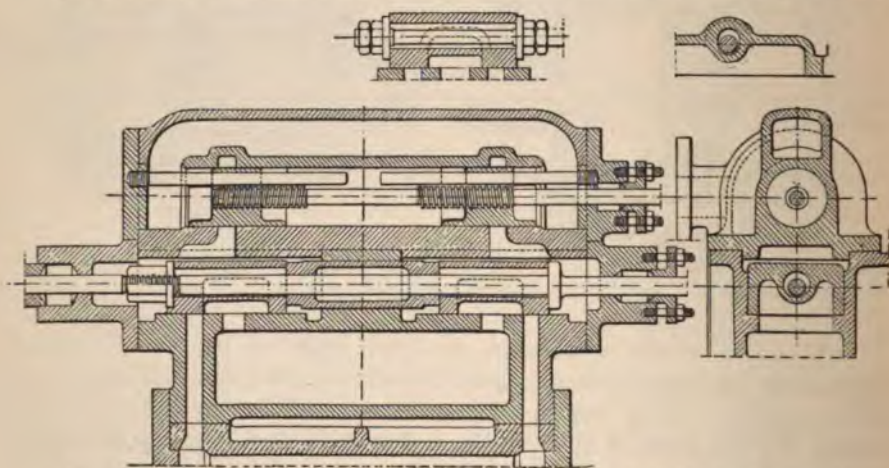
Figs. 581.—Warner & Sons: Main Slide and Expansion-valves on 1st and 2d Cylinders. Scale 1/8th.

5½ inches cast on the cylinder, from the exhaust-chamber of the cylinder to the exit at the top of the cylinder 2½ inches in diameter, whence it passes by a 2½-inch cast-iron pipe, ⅜ inch thick, to the valve-chest of the

second cylinder.   This pipe, figs. 582, is, for its upper half, covered by a semi-annular steam-space ¾ inch wide, by which steam brought by a 1¼-inch tube from the boiler is conveyed to each of the steam-jackets of the cylinders. Heat is thus imparted to the steam in course of transmission from the first to the second cylinder in addition to the heat it derives from exposure to steam-jacketed surface in both the cylinders. The intermediate
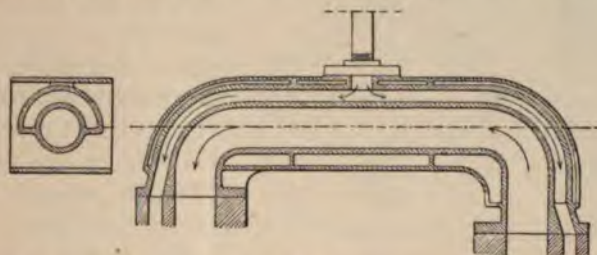
Figs. 582.—Warner & Sons: Exhaust-pipe from First to Second Cylinder. Scale 1/12th.

pipe and steam-way are cased in a square inclosure, as in figs. 582, filled with felt or with boiler composition.

From the second cylinder the steam is exhausted and conducted in a 3-inch cast-iron pipe, ⅜ inch thick, to the condenser. The condenser, figs. 583, is an upright cylindrical vessel of cast iron, of ½-inch metal, with a domical head, 9 inches in diameter and 10 inches high internally.   The condensing water is delivered into the condenser at the opposite side, through the injection-pipe, the end of which is globular, perforated with
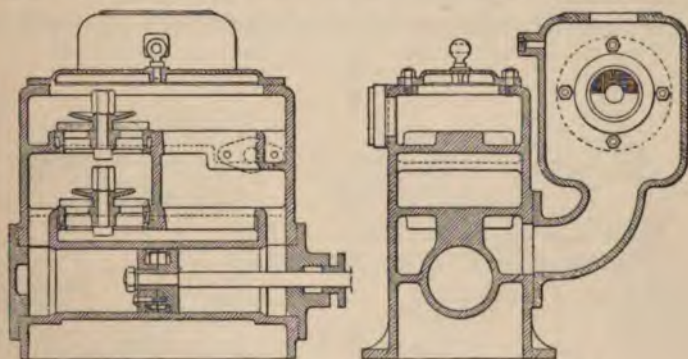
Figs. 583.—Warner & Sons: Condenser and Air-pump. Scale 1/12th.

small holes over the upper half, so as to deliver the water in every direction as a thick spray, meeting the steam which enters above it.   The supply of injection-water is regulated by means of a globular screw-down valve. The water and vapour pass through the bottom by a 3-inch passage into the air-pump inclosure.

The air-pump, figs. 583, is contained in a cast-iron chest 17½ inches long, 9 inches wide, and 17½ inches high, outside measure; of ½-inch metal. The pump is double-acting, of ½-inch metal, 4 inches in diameter, with a

stroke of 12 inches. The barrel is connected by a horizontal web-plate to each side of the case, forming a bottom chamber into which the water flows from the condenser. There are two suction-valves—the lower tier—and two delivery-valves, placed over the barrel. By the suctional action of the pump, which is fitted with a close piston, the water is drawn through the suction-valves, and downward at each end of the barrel alternately, into the barrel, following the piston; and on the return-stroke, it is forced back into the second chamber and through the delivery-valves into the uppermost chamber, whence it overflows by a 3-inch pipe. The piston is 2½ inches thick, and is in two pieces, bolted together, forming a groove 1½ inches wide, for Mather & Platt's packing: comprising a steel coil and phosphor-bronze angle-rings. The pump-rod is of brass, 1 inch in diameter, and is reduced to ¾ inch in the piston, and fastened by a collar-nut. It passes through a stuffing-box in the back of the second cylinder, and is connected to the piston-rod by a thick nut, as subsequently described. The valves are india-rubber discs, ½ inch thick and 5¾ inches in diameter, falling upon gun-metal gratings 5 inches in diameter.

Figs. 584.—Warner & Sons: Pistons. Scale 1/8th.
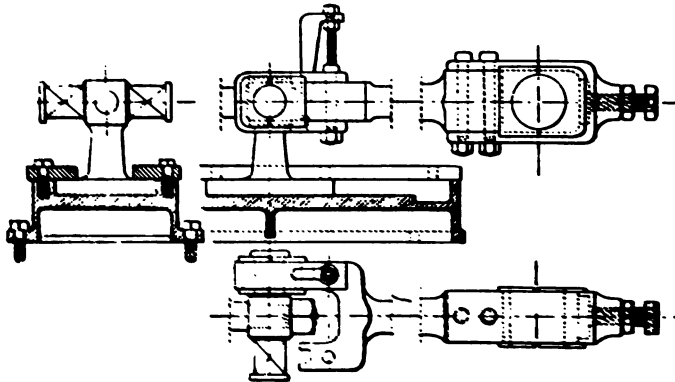
Figs. 585.—Warner & Sons: Crosshead and Connecting-rod. Scale 1 10th.

The steam-pistons, figs. 584, are of cast iron, having Mather & Platt's packing-rings. The second piston-rod is fastened by a deep nut, recessed into the piston, into which the air-pump rod is screwed up against and jamming the piston-rod. The joint is inside the cylinder.

The crosshead, figs. 585, has two journals, and is supported on a slipper

or slide in one forging with it, all of steel, 7 inches long.   The slide is held down by an overhung bar screwed to the ledges of the guide-bar, which is of cast iron.

The connecting-rod, figs. 585, is of wrought iron, 2 feet 11½ inches long, or about six times the length of the crank, fitted with brasses of phosphor-
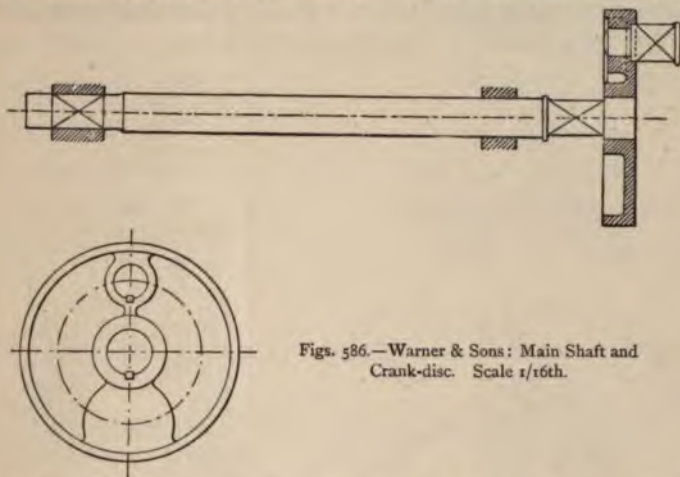
Figs. 586.—Warner & Sons: Main Shaft and
Crank-disc.   Scale 1/16th.

bronze.   The bearings are 3 inches in diameter by 3¼ inches at the crank-end, and 1¾ inches by 2 inches at the smaller end.

The main shaft, figs. 586, is of steel 3½ inches in diameter, with a cast-iron crank-disc of ¾-inch metal in the face, shrunk on the shaft and fastened with one key.   The crank-pin is of steel, 3 inches in diameter.   The fly-wheel is 6 feet in diameter and 6 inches wide at the rim, which is 1¼ inches
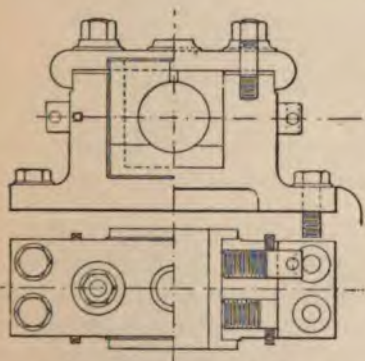
Figs. 587.—Warner & Sons: Main Pedestal.
Scale 1/8th.
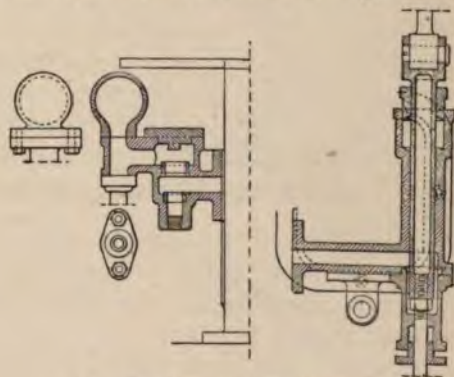
Figs. 588.—Warner & Sons: Feed-pump.
Scale 1/12th.

thick.   It has six arms, and it weighs 10 cwts.   The pedestal, figs. 587, is fitted with brasses, square in outline, in three pieces: two adjustable side pieces and a bottom piece.

The eccentrics and their straps for the valve-gear, figs. 590, are of cast iron, 7 inches in diameter.   The main eccentric-rod is utilized to work the

feed-pump, figs. 578, 588, and 590, which is placed in line between the eccentric and the main slide-valve. The plunger is pinned to the eccentric-rod, and at the other end the valve-rod is screwed into it and secured with a jam-nut, the rod working through a stuffing-box. A 3-inch spherical air-vessel is fixed on the delivery-pipe.

The expansion-valve is, as before stated, regulated automatically by the governor, figs. 589, which is on Rackham's system. There is a central
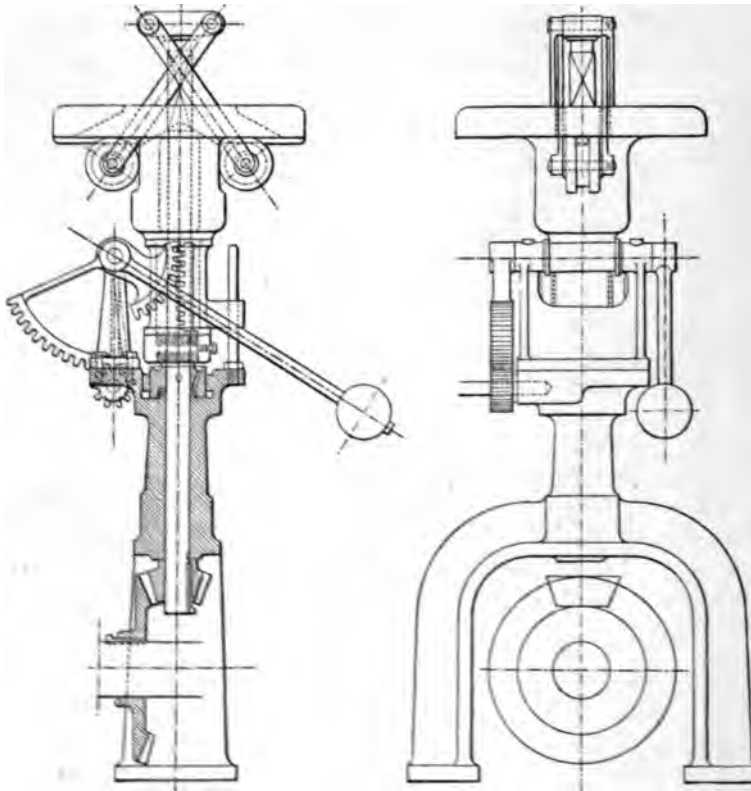
Fig. 589.—Warner & Sons: Rackham Governor.   Scale 1-12th.

weight or disc, 16 inches in diameter and 2 inches thick, supported on two roller weights or "balls," suspended by cross arms. As the rollers diverge or collapse, according to the speed and centrifugal force, they simply turn on their central pins and roll along the under side of the disc, lifting or lowering it. The upper part of the governor-spindle is squared, in order to cause the weight to revolve, so preventing cross strains on the joints of the suspension links, while the weight is free to rise or fall. For a like purpose, of causing the rollers to revolve, they are grooved at the circumference, to work over reeds fixed radially to the under side of the disc, and so are carried round with the disc-weight.

On a sleeve on the bottom of the disc-weight two vertical racks are cast one on each side, which gear into two quadrants, on the axis of which

a toothed segment of larger radius is fixed, which turns a small shaft by a pinion fixed on it.   From this shaft, by two intermediate pairs of bevel-wheels, the spindle of the expansion-valve is caused to rotate: the spindle being formed 1 inch square, where it passes through the sleeve of the last mitre-wheel, and so receiving and transmitting the rotation movements impressed by the governor, whilst it is free for the reciprocating motion of
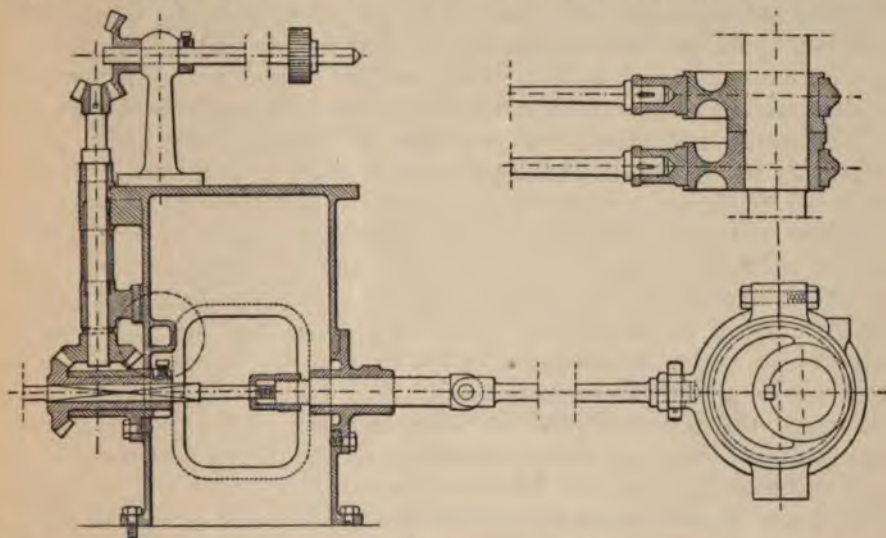
Figs. 590.—Warner & Sons: Intermediate Gearing between Governor and Expansion Valve-spindle.   Scale 1/10th.

the eccentric.   The spindle is in two parts, connected near the squared portion by a swivel-joint.   The part which is pinned to the eccentric-rod, 1½ inches in diameter, is supported in a cast-iron guide.   See also figs. 590.

The governor is provided with a weighted lever, by means of which the engine can be instantly stopped, if required, without shutting off steam, by raising the lever by hand.   A cord can be attached to this lever and led to any room at a distance where machinery is worked by the engine; and, in case of an accident, the engine can be instantly stopped by any one in the room.

The governor is driven by means of bevel-gearing direct from the main shaft, and it makes 305 revolutions per minute.   The maximum variation of speed is stated to be about 4 per cent.

The weight of the engine complete is 45 cwts., of which the fly-wheel weighs 10 cwts.   The price is £215, or about £95, 10s. per ton.

Nominal power is calculated at the rate of 12½ square inches of area of the second cylinder per horse-power.   But the rule is not strictly followed.

CHAPTER XXII.—HORIZONTAL TANDEM COMPOUND STEAM ENGINE, OF 25 HORSE-POWER.

CONSTRUCTED BY MESSRS. SPENCER & CO., MELKSHAM.

(Cylinders 12½ inches and 22 inches diameter, 30 inches stroke.)

This tandem engine was designed by Mr. John Gillett, for compactness, and facility for examination and repair. The first and second cylinders are placed unusually near to each other, and are joined by a circular piece, with which are cast in one the adjacent covers of the cylinders, with their stuffing-boxes and glands, and a means of tightening the glands simultaneously by a vertical wedge-and-screw motion. The second cylinder and the condenser are similarly connected; and these are bolted to a cast-iron bed-plate, formed with longitudinal grooves, in which the heads of the bolts, when slackened, may slide, and so admit of the removal of the condenser or the second cylinder along the bed to a greater distance apart, for inspection. For this purpose they are each provided with a spur-pinion, which gears into a rack in the bed-plate; and, when the nuts of either cover are taken off their bolts, and the sliding bolts slackened, the second cylinder and the condenser, or the condenser alone, can be racked back any desired distance, and the pistons withdrawn. The first cylinder is suspended between the second cylinder and the frame. The frame is tubular, to carry the slide-guides, and is formed with a circular flange to join the cylinder-end with bolts and nuts. The other portion of the frame is of a box form, and the whole frame rests solidly on the foundation.

The cylinders are respectively 12½ inches and 22 inches in diameter, the areas being in the ratio of 1 to 3.09, with a stroke of 30 inches. They are of ⅞-inch metal, and the steam-jacket, applied only on the first cylinder, is of 1-inch metal. The air-pump is double-acting, and is 7 inches in diameter, with a stroke of 30 inches.

The connecting-rod is 6½ feet long, or 5.20 times the length of the crank. The fly-wheel is 10 feet in diameter. An ordinary slide-valve is applied to each cylinder for the distribution of the steam, and the two valves are worked by one eccentric on the main shaft. The eccentric-rod actuates a small crosshead on a rocking carrier, from each end of which the valve-spindles are moved by connecting links. The space occupied longitudinally by the parts of the engine are here given, as means of comparison.

	Feet.	Inches.
Centre of main shaft to face of first cylinder	9	5¾
Length of first cylinder from face to face	3	3⅝
Interspace	1	4
Length of second cylinder from face to face	3	5¼
Interspace	0	10
Length of condenser	3	6¾
Total length from main shaft	21	11⅜

The speed is at the rate of 86 turns, or 430 feet of piston, per minute. The pressure in the boiler is 65 lbs. per square inch, and the steam is cut off at half-stroke. The engine complete weighs 13 tons, including 3¾ tons, the weight of the fly-wheel. The price is £460, or £35, 8s. per ton of weight.

CHAPTER XXIII.—HORIZONTAL COMPOUND RECEIVER STEAM ENGINE.

DESIGNED BY MR. DRUITT HALPIN, LONDON; CONSTRUCTED BY MESSRS. MANLOVE, ALLIOTT, FRYER, & CO., NOTTINGHAM.

(Cylinders 9 inches and 14 inches in diameter, stroke 21 inches.)

This engine is distinguished chiefly by its peculiar valve-gear, comprising a species of rocking valve for the first cylinder; and the construction of the cylinders with circular ribs or flanges on the outside, called heat-ribs, in order to accelerate the conduction of heat from the steam-jacket into the cylinders.[1] The section, fig. 591, of the first cylinder shows the annular ribs, nine in number, and the cylinders and steam-jacket are shown in transverse section, fig. 592. The complete steam-jacketing of the cylinders is specially provided by placing the cylinders and covers entirely
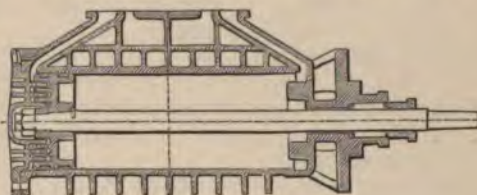
Fig. 591.—Halpin: First Cylinder. Scale 1/18th.

inside a steam-jacket, as partly shown in fig. 592; the joints of the cylinder-cover being made within the casing, which has covers of its own. There is no valve-chest for the first cylinder, which takes steam direct from the jacket. Steam is exhausted from it into the second cylinder through a pipe or passage, of a flat rectangular section, which winds upwards and downwards. This pipe and the valve-chest of the second cylinder together constitute the intermediate receiver, the whole being completely enveloped in
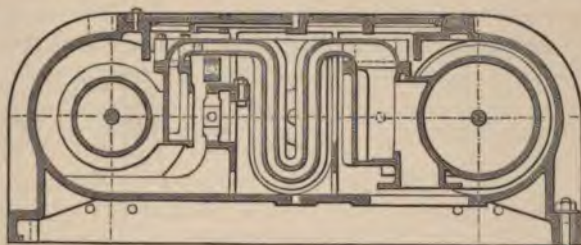
Fig. 592.—Halpin: Cross Section of Cylinders. Scale 1/24th.

the jacket. The jacket is drained by a steam-trap. The cylinders are respectively 9 inches and 14 inches in diameter, with a stroke of 21 inches. They are placed 3 feet 9 inches apart between centres, the intermediate space being occupied by the receiver. The total clearance in the first cylinder is 5.3 per cent at the front end, and 6.2 per cent at

[1] See *Engineering*, April 21, 1882, page 392, for a full account of this steam engine.

the back.   In the second cylinder it is 5.4 per cent at the front, and 6.2 per cent at the back.

The engine was erected at Nottingham for experimental purposes, and was supplied with steam from a boiler of the locomotive type, of which the grate was reduced by fire-brick, for the occasion, to 4.6 square feet of area, and the total heating surface was 326.33 square feet.   It was connected with a Twibill economizer.   Two trials of the engine were made at Nottingham, of which the leading results, derived from *Engineering*, are as follows:—

Mr. Druitt Halpin's Horizontal Compound Receiver Engine.

	March 1, 1882.	March 15, 1882.
Date of trial		
Duration of trial.......................................	8 hours.	8 hours.
Average steam-power in boiler	65.6 lbs.	65.1 lbs.
Do. vacuum in condenser	27.33 ins.	28.09 ins.
Height of barometer..................................	28.65 „	30.40 „
Average speed in turns per minute................	95.90 turns.	96.87 turns
Do. do. in feet of piston per minute	335.65 feet.	339.0 feet.
Indicator horse-power in first cylinder............	14.5 H.P.	17.66 H.P.
Do. do. second cylinder	16.7 „	23.04 „
Do. do. together....................	31.2 „	40.70 „
Brake horse-power....................................	27.05 „	34.14 „
Do. per cent of indicator power ...	86.7 per cent.	83.9 per cent.
Water discharged from steam-jacket per hour...	89.45 lbs.	97.67 lbs.
Do. do. per indicator horse-power	2.86 „	2.39 „
Feed-water, average temperature in tank.........	69°.7 Fahr.	73°.4 Fahr.
Do. evaporated per hour...................	545.1 lbs.	756.5 lbs.
Do. do. do. per sq. ft. of fire-grate		
Do. do. per indicator horse-power	17.47 „	18.58 „
Do. do. per pound of coal.......	10.86 „	10.30 „
Coal consumed per hour.............................	50.2 „	73.4 „
Do. per square foot of fire-grate	12.36 „	14.46 „
Ash and clinker per cent of coal...................	6.1 per cent.	5.3 per cent.
Temperature in the smoke-box....................	382°.4 Fahr.	392°.3 Fahr.

Sample indicator diagrams, taken during the first trial, are reproduced
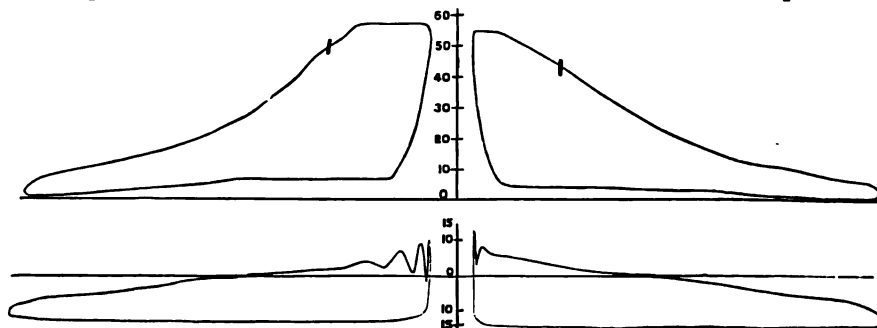
Figs. 593.—Halpin: Sample Indicator Diagrams.

in figs. 593, representing a fairly average rate of work done.   The pressures indicated are as follows:—

FIRST CYLINDER.	Front (next the crank).	Back.
Maximum pressure above the atmospheric line....	59½ lbs.	57 lbs.
Period of admission	25 per cent.	20 per cent.
Initial pressure at cut-off..............................	51 lbs.	44½ lbs.
Final pressure, as for the end of the stroke.........	6 ,,	4½ ,,
Nominal ratio of expansion............................	4.00	5.00
Actual ratio of expansion	3.47	4.05
Ratio of total initial and final pressures.............	3.21	3.12
Period of compression..................................	9 per cent.	7½ per cent.
Pressure at point of compression, above atmospheric line...	7 lbs.	5 lbs.
Weight of steam cut off.................................	.03624 lb.	.02836 lb.
Do. do. expanded.............................	.04194 ,,	.03934 ,,
Difference...	.00570 ,,	.01098 ,,
Do. per cent of expanded steam..............	13.59 per ct.	27.91 per ct.
Steam retained by compression	.000597 lb.	.000481 lb.
Deducted from weight of expanded steam, leaves, net, for one double-stroke.........................	.08020 lb.	

SECOND CYLINDER.

	Front	Back
Final pressure, as at the end of the stroke, below the atmospheric line	6½ lbs.	6½ lbs.
Do. do. absolute (14.33 lbs. – 6½ lbs. =).	7.83 ,,	7.83 ,,
Weight of steam expanded............................	.04137 lb.	.04137 lb.
Do. do. for one double-stroke	.08274 lb.	

FINAL RESULTS.

Net weight of steam consumed, as indicated, per hour in the 1st cylinder (95.9 turns per min. × 60 minutes × .0802 lb. =)	461.50 lbs.
Add, consumed in steam-jacket, per hour.........................	89.45 ,,
Steam consumed as indicated, and in jacket	550.95 ,,
Water consumed per hour, by measurement......................	545.10 ,,
Excess indicated	5.85 ,,
Do. do. per cent of measured consumption...........	1.07 per cent.
Calculated for the 2d cylinder, the steam consumed as indicated, and in jacket, is..	565.55 lbs.
Water consumed per hour, by measurement......................	545.10 ,,
Excess indicated	20.45 ,,
Do. do. per cent of measured consumption	3.75 per cent.

The boiler was worked much below its normal rate of performance, and there was no likelihood of priming from it. On the contrary, the whole of the water evaporated is fully explained by the foregoing analysis. The considerable proportion of steam condensed and re-evaporated— 3.59 per cent at the front end of the first cylinder, and 27.91 per cent at the back end—proves conclusively that jacketing by steam, however completely effected, is only a cobble, and but partially a preventive of initial condensation. The shorter admission and longer expansion shows twice as

much condensation as the longer admission. The contrast points to the disadvantage of cutting off earlier than at one-fourth of the stroke. Nevertheless, the thorough jacketing of the cylinders has effected the complete resuscitation of the steam condensed during admission; even slightly superheating the steam, as suggested by the fact that the apparent quantity of steam in evidence at the end of the stroke, plus the steam condensed in the jacket, is greater than the whole quantity evaporated. But this evidence is not conclusive, since the indicator diagrams, figs. 593, on the values of which the estimate of steam as indicated is based, are only accepted as approximately average samples, and may not represent the exact average action of the steam for the whole of the trial.

Although the inferior expansive action of the steam for the shorter admission—which took place for the back of the cylinder—is but consistent with what has before been determined, it is to be remarked that the superficies of the back-cover of the cylinder is largely developed by the use of the heat-ribs; and it is open to question whether this was not in fact a development of condensing surface, acting on the steam when admitted, and that what was designed as a superheater did not act as a condenser. It is probable that the excessive condensation proved by the indicator diagram, was caused, in part at least, by the great development of metal-surface, not only in the cover, but also in the piston.

STATIONARY STEAM ENGINES OF GREAT POWER FOR LARGE MILLS.

CHAPTER XXIV.—HORIZONTAL CONDENSING CORLISS-VALVE STEAM ENGINE, FOR 1000 INDICATOR HORSE-POWER.

CONSTRUCTED BY MESSRS. HICK, HARGREAVES & CO., BOLTON.

PLATE VI.

(Cylinder 40 inches diameter, 10 feet stroke.)

This engine was constructed for the Whetley Spinning Mills, Bradford, the property of Messrs. Daniel Illingworth & Sons; for a pressure of 80 lbs. per square inch in the boiler. The cylinder is 40 inches in diameter, with a stroke of 10 feet, or three times the diameter, making 45 revolutions per minute, equivalent to a speed of piston of ($10 \times 2 \times 45 =$) 900 feet per minute. The fly-wheel is 30 feet in diameter, and it drives from its circumference, which is grooved for 27 ropes, transmitting the power direct to the several line-shafts in the mills. The cylinder is bolted to a massive cast-iron frame, on the Corliss principle, connecting the cylinder directly to the main shaft. The cylinder and the frame are supported by feet direct on the foundation. The main shaft pedestal is formed with a broad base resting on the foundation. The castings are made of Scotch pig-iron, with a mixture of hematite. The proportions of the mixture vary within wide limits, depending upon the qualities required in the casting.

The foundation is formed up to one uniform level, and the centre-line of the engine is 4 feet high, above the foundation-level.

The cylinder, figs. 594, 595, and 596, is designed with Corliss valves, worked by Inglis & Spencer's liberating gear, seen in fig. 594. It is constructed in four pieces, as already described for the Woolwich engine, constructed by the same firm, page 43, comprising a separate liner or working barrel, of hard cast iron, a separate steam-jacket casing, and, in addition, two cylinder-covers. The cylinder is 1⅝ inches thick, the jacket is 1⅜ inches thick, and the interspace for steam 1¼ inches wide. The covers are hollow, forming steam-jackets. They are of 1-inch metal, except in the outer disc of the front cover, which is 1½ inches thick at the stuffing-box, tapering to 1¼ inches thick at the circumference. The flanges of the covers, by which they are bolted to the cylinder, are 2 inches in thickness. The clear length of the cylinder, between the covers, is 10 feet 11 inches, being 1 inch more than the length of the stroke, 10 feet, plus the thickness of the piston, 10 inches; or 10 feet 10 inches together, with ½ inch direct clearance between the piston and each cover, at the beginning of each stroke. The working cylinder, or barrel, is 10 feet 9 inches long, or 1 inch less

than the length of the stroke plus the thickness of the piston.   The piston overshoots the barrel at each end by half an inch, so tending to equalize wear, and clearing out of the barrel any dirt or sediment that gets into it.   The direct clearance, ½ inch at each end, is about 4/₁₀ths of one per cent of the length of the stroke.   The total clearance, including the passages to the steam-valve and exhaust-valve, amounts to 1.54 per cent.

The jacket is 9 feet 8½ inches long between the end-rings. These are respectively 12½ inches long at the front end, and 11½ inches long at the back end, the difference, 1 inch, being due to the greater thickness of metal of the front ring where the frame is bolted to it. The three pieces, taken together, make up the total length of the cylinder, 11 feet 8½ inches.

The working barrel is not bolted to the ends; it is simply held in place between the end-rings by the jacket, which is fixed to the rings by thirty 1-inch stud-bolts and nuts, at about 57/₁₆ inches of pitch. Each cover is bolted to the end-ring with twenty-four 1¼-inch stud-bolts and nuts, at nearly 5¾ inches of pitch.   The stuffing-box on the front cover is 11 inches in diameter, with 9¼ inches of net depth.   That on the back cover is 10½ inches in diameter, with 7 inches of net depth; in each case a stuffing space 1½ inches wide round the piston-rod. They are bushed with brass, and have brass-bushed glands of cast iron. Packings of plaited hemp gasket are used in the stuffing-boxes. The cylinder-castings are tested by hydraulic pressure, and with steam also in the jacket.
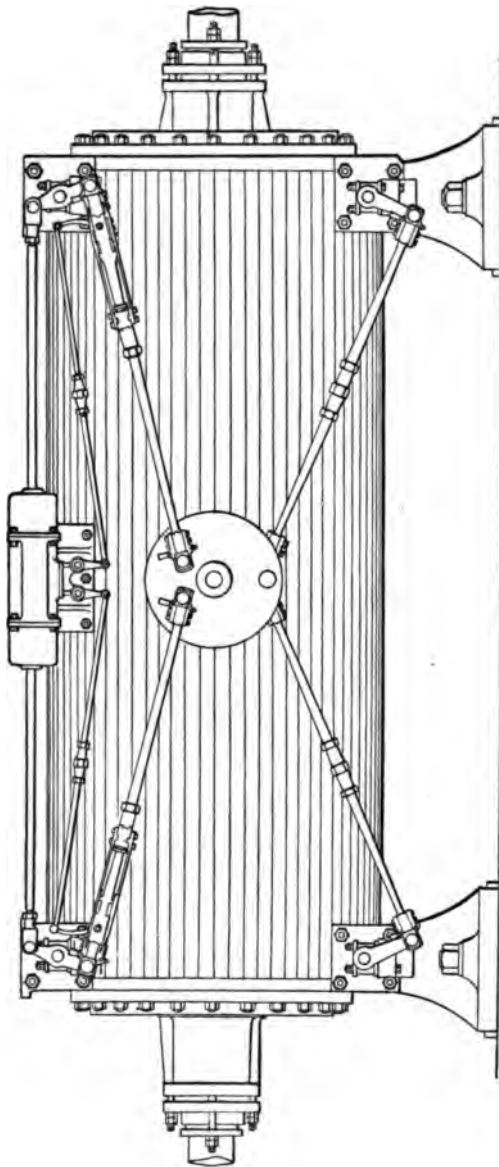
Fig. 594.—Hick, Hargreaves & Co.: Side Elevation of Cylinder, showing the Liberating Gear.   Scale 1/32d.
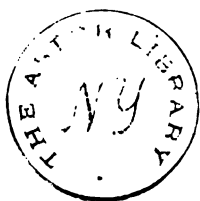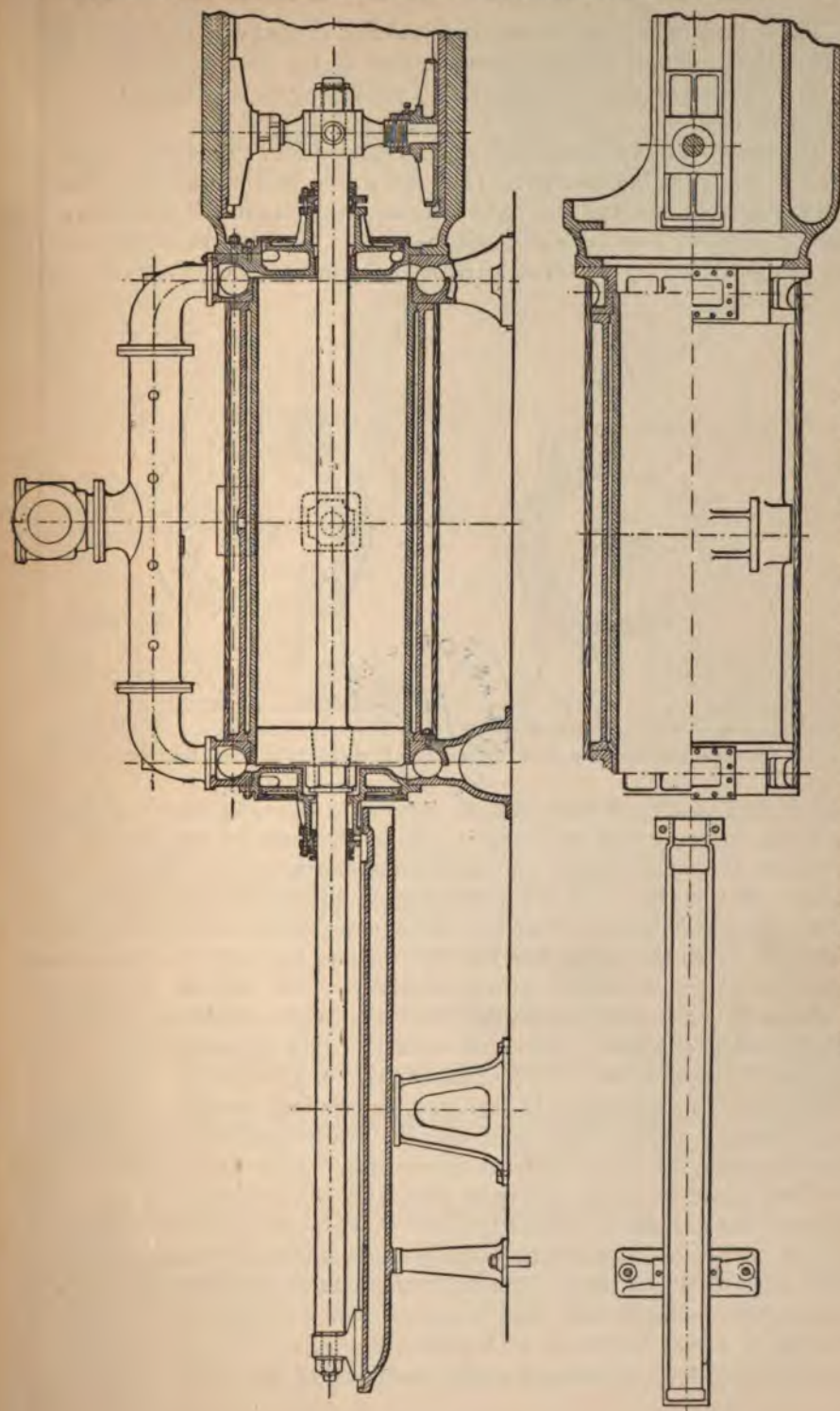
Figs. 595.—Hick, Hargreaves & Co.: Cylinder, Sectional Elevation and Plan. Scale 1/48th.

The cylinders and the covers are felted and lagged with mahogany laths ¾ inch thick,—applied to the circumference of the flanges, and forming a 3-inch air-jacket on the steam-jacket. The lagging on the covers is covered with sheet-iron.

The steam-valves and exhaust-valves rotate in four cylindrical chambers, bored to 8 inches in diameter. They are shown in elevation and section, with the gear, in figs. 594 and 597. The steam-ports are 2 inches wide; the exhaust-ports are 4 inches wide; and they have a total length of 34½ inches. But being divided by two cross partitions 1¼ inches thick, their net length
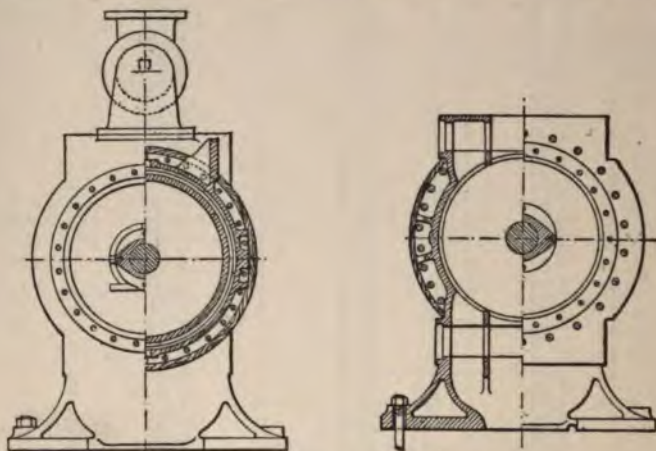
Figs. 596.—Hick, Hargreaves & Co.: Cylinder, Cross Sections and End Views. Scale 1/48th.

is 32 inches, making a net sectional area of ($32 \times 2 =$) 64 square inches for the steam-ports, equal to about $1/_{20}$th of the area of the piston; and ($32 \times 4 =$) 128 square inches for the exhaust-ports, equal to about $1/_{10}$th of the area of the piston. Each valve is 38½ inches long, overlapping the ports at each end to the extent of 2 inches; the steam-valve has 4¼ inches of straight width across the face, having 1 inch of lap, with $1/_{16}$ inch of lead, and $4^{13}/_{16}$ inches of travel circumferentially. The volume of the total clearance between the piston and the valve is, at the front, 2196 cubic inches; and, at the back, 2283 cubic inches; or 1.54 per cent of the working capacity of the cylinder. Each exhaust-valve is a little more than a semi-circle in section, as shown in figs. 597, presenting nearly a semicircular cavity, leaving clear, when fully opened, nearly half the section of the valve-chamber, for a free exhaust downwards. They have ⅞ inch of lap, with lead equal to about half-open port, and $59/_{16}$ inches of travel. The shafts of the valves, by which they are moved, are 2 inches in diameter, reduced to 1½ inches for the stuffing-boxes, and for the outer bearings, which are 3½ inches long. The shaft of each steam-valve is formed with a rectangular palm at each end, 2 inches wide and 6 inches long, giving 3 inches of radial length on each side of the axis. It is lodged within a corresponding loop, 2 inches long, at each end of the valve, and so com-
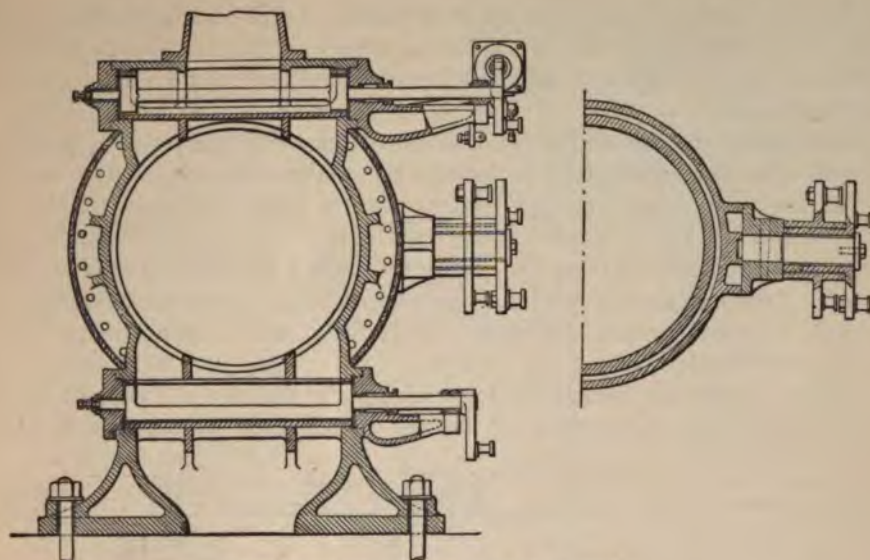
Cylinder and Valves, Cross Sections.   Scale 1/32d.
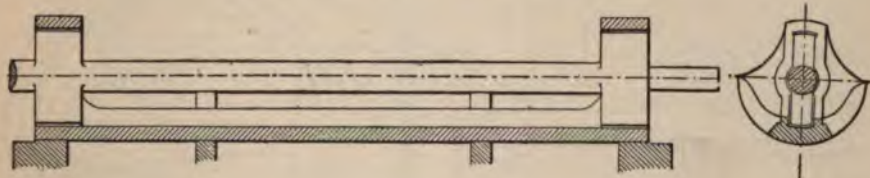
Admission-valves.   Scale 1/12th.
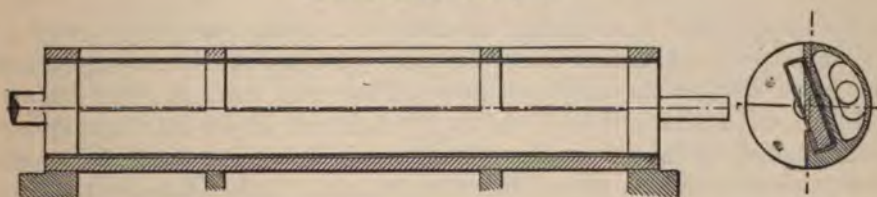
Exhaust-valves.   Scale 1/12th.

Figs. 597.—Hick, Hargreaves & Co.: Corliss Valves.

mands it. The exhaust-valve shaft is formed for the whole length of the valve as a rectangular bar in section, of which one angle is partly bevelled off, as shown in figs. 597, so as to form an unobstructed passage-way for exhaust steam.

The lever on the end of each steam-valve shaft has arms of unequal length—the lower arm, 5½ inches long, to take the reciprocating movement, and the upper arm, 4½ inches, for the dashpot connection. It is 1¾ inches thick, and carries a 1½-inch stud-pin, shrunk into it, for the valve-rod. The journal on the pin is 1½ inches in diameter and 2 inches long. Each exhaust-valve derives its reciprocating movement through an arm of 8 inches radius, 1¾ inches thick, fitted with a stud-pin like that of the steam-valve shaft.

The lines of the mechanism for working the valves are shown in figs. 2 and 3, Plate VI. The valves are worked by separate connections, through
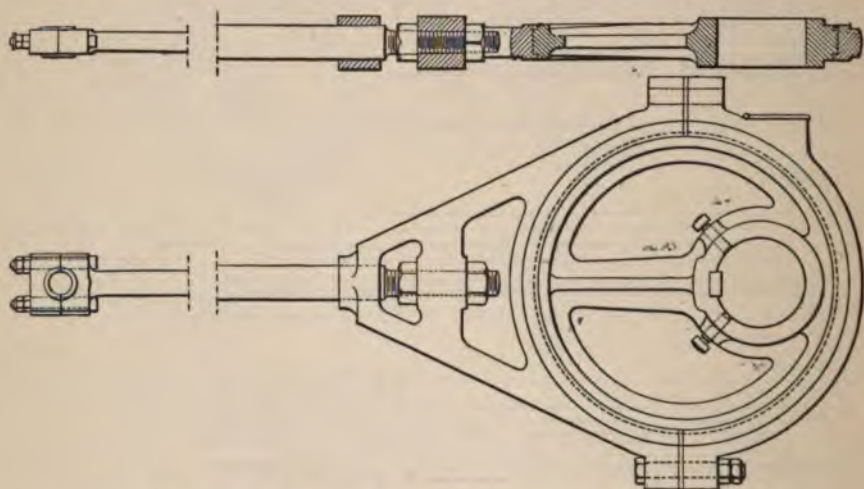
Figs. 598.—Hick, Hargreaves & Co.: Eccentrics and Rods.   Scale 1/16th.

two independent "wrist-plates," or discs with crank-pins, 22½ inches in diameter, and 1½ inches thick: the outer disc for the steam-valves, and the inner disc for the exhaust-valves. They take their bearings on and oscillate on a stud-pin, 4½ inches in diameter, keyed into a cast-iron socket bolted to the side of the cylinder, as in figs. 597. Each disc carries two 1½-inch stud-pins shrunk in, with journals 2 inches long to take the valve-rods; also one larger crank-pin, 2 inches in diameter, with a journal 2¼ inches long, fixed to the disc with a nut, to take the end of the eccentric-rod by which it is moved.

The oscillating discs receive their reciprocating movements from two separate cast-iron eccentrics, figs. 598, one for each, 25½ inches in diameter and 2¾ inches wide, having a throw of 12¾ inches; keyed on a short shaft, 7½ inches in diameter, supported by the frame, and driven by bevel gear from the main shaft. The first pair of wheels are as 2 to 1, causing

the horizontal gear shaft to make twice the number of turns made by the main shaft, to give the correct speed for the governor, for which the motion is taken off by mitre-wheels. The speed is, of course, reduced to one-half, or to the speed of the main shaft, to drive the eccentrics, from which the motion is taken direct to the wrist-plates. The eccentric-hoops are of cast iron. The eccentric-rods are 9 feet $10\frac{3}{4}$ inches in length between the centre of the eccentric and the end centre. They are $2\frac{3}{4}$ inches in diameter, tapered to $1\frac{3}{4}$ inches at the far ends. They pass through a socket on each hoop, and are adjustable in length by means of nuts within the hoops, and are each finished with a cap and $\frac{7}{8}$-inch bolt bearing to take the crank-pin on the oscillating disc.

The valve-rods connecting the valve-arms with the wrist-plates are shown in detail in figs. 599. Their construction has already been described generally at pages 45 and 46. In the present instance the steam valve-rods are 5 feet $4\frac{3}{8}$ inches long between centres, and the ex-
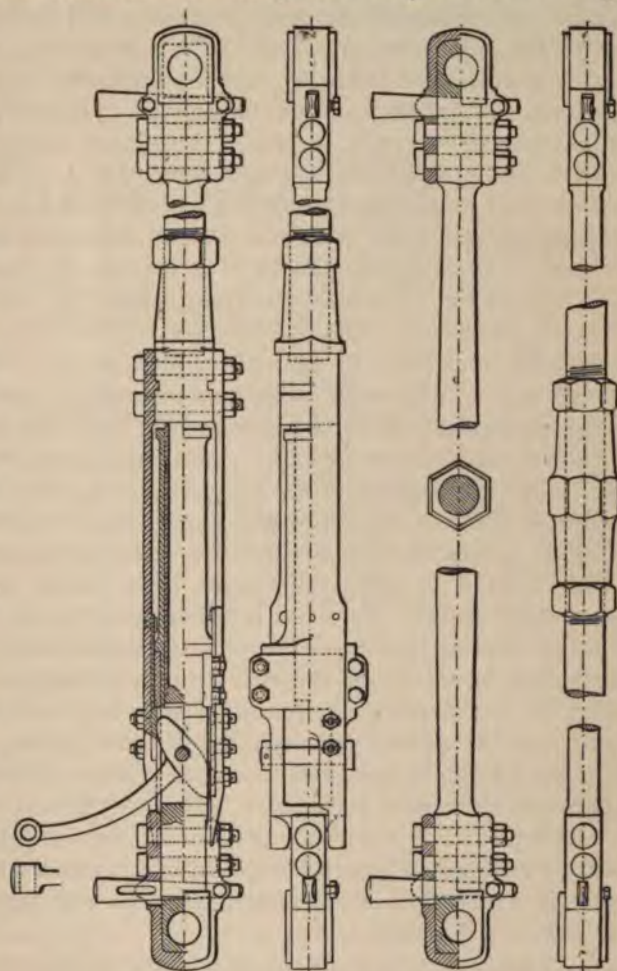
Steam Valve-rods.   Exhaust Valve-rods.
Figs. 599.—Hick, Hargreaves & Co.: Valve-rods. Scale $\frac{1}{8}$th.

haust valve-rods are 5 feet $3\frac{1}{2}$ inches in length. They are adjustable in length by means of right-and-left-hand screws and a double-nut for the exhaust valve-rods, and a screw and jam-nut on the steam valve-rod. The disengaging-rods also are adjustable in length by means of a right-and-left-hand screw and a nut on each. Each end of the valve-rods has brass bearings with a butt and strap fastening; the bearings being 2 inches wide to fit the wrist-pins, and the butt and strap $1\frac{1}{2}$ inches wide.

The strap is fastened to the butt with two ⅝-inch bolts and nuts, with a split pin through the end of each bolt behind the nut. The brasses are fixed by a cotter ½ inch thick, 6 inches long, and tapered ½ inch in the length, or at the rate of 1 in 12, secured in place with two ⅜-inch set-screws. The rod is in two portions, one capable of sliding within the other, as before explained; of which the disengaging portion is tubular, 1½ inches in diameter internally, to receive the solid cylindrical end of the other portion. This cylindrical end is 1¼ inches in diameter, and is coated with brass ⅛ inch in thickness, making up the external diameter, 1½ inches. When home, the cylinder penetrates the socket to the extent of 11½ inches—a length of contact which ensures the stability of the structure for longitudinal thrust. The base of the cylinder is developed as a square block, 2½ inches square, to which the spring-clips are joggled, and fixed with two ⅝-inch bolts and nuts. The clips have 18 inches of clear length, and are of steel plates 5/16 inch thick and 2½ inches wide, expanding in width to 3⅛ inches for the disengaging action. They are lined each with a wearing piece ¼ inch thick, fixed with counter-sunk bolts and nuts, to take the action of the liberating cams, and to engage edge to edge with corresponding wearing pieces bolted to the body of the valve-rod. Thus the spring-clips, one with the wrist-plate portion of the valve-rod, engage with and pull the disengaging or valve end of the rod, by the intervention of the wearing pieces, which are 3⅛ inches wide— the whole width of the clips—and engage each other for a depth of ⅛ inch. In order, therefore, to disengage the spring-clips, and break continuity, it is only needful to press them apart by a quarter of an inch. Then the disengaging portion of the rod is pulled back by the action of the dashpot, and the wearing pieces of the clips slide over those of the rod. By the advancing movement of the eccentric, the wrist-plate portion of the rod, and with it the clips, are pushed up towards and over the disengaging portion, and the wearing pieces fall again into pulling order. In collapsing, or falling back into gear, they fall upon leather surfaces, by which the blow is softened and sound is subdued. The wrist-plate portion of the valve-rod is in two pieces, of which the piece next the wrist-plate is screwed into a socket bored out of the other piece, which carries the spring-clips. The screw is 1¾ inches in diameter, and the rod tapers to a diameter of 1⅜ inches at the butt.

The fulcrum of the disengaging cam-lever is a ¾-inch pin passed through the valve-rod, which is slotted out to receive the centre of the lever and the cams. The cams are each 2 inches long, measured from the centre of the pin, and the lever has a radial length of 7⅜ inches, or 3.7 times the length of the cams. But the real leverage is the ratio of the space traversed by the end of the arm to the lift of the spring-clips; or as $^{11}/_{16}$ inch to ⅛ inch, or 5½ to 1.

The dashpots, one for each end of the cylinder, figs. 600, are placed end to end above the wrist-plate; and are supported by brackets from the upper part of the cylinder. The cases are of cast iron, cylindrical, bored to 7 inches

in diameter, and each case is 12½ inches long internally; the middle piece being ½ inch thick, and the two outer pieces ⅜ inch thick. The partition between the bottoms of the cases is 1 inch thick. A brass piston fitting each case well, but easily, works in the case, and is formed with a tubular trunk, 2¼ inches in diameter, which works through and is guided by the outer piece or cover of the dashpot. The piston is held against the bottom of the dashpot by a helical spring of ⅜-inch square steel, coiled to a diameter of 5¼ inches externally, constantly in a state of compression. Through four ½-inch air-holes in the cover, air is free to circulate, as the piston advances and recedes. There are also four ½-inch holes in the casing of each dashpot, about ¾ inch from the bottom. When the piston passes and closes these holes the remaining air is imprisoned and cushions the piston. There is an adjustable valve to let off the air gradually. The pulling rod for each dashpot is 1 inch in diameter; but it is flattened, for a portion of its length, within and without the trunk, to the section 1⅝

Figs. 600.—Hick: Dashpots. Scale 1/16th.

inches by ½ inch. By such flattening, some degree of flexibility is imparted to the rod, in order to accommodate it easily to the sway of the upper arm on the valve-shaft, to which it is connected by a 1¼-inch pin. The rod is passed through the bottom of the piston, and is secured to it by a countersunk nut, which is prevented from turning by a small screw let half into the nut and half into the piston. The rod is adjustable in length by a screw and jam-nut.

The toothed sectors, by means of which the disengaging rods are shifted in unison, are mounted on 1¼-inch shafts, and have a radius of 2½ inches, with ⅜ inch pitch of the teeth. The arms on the shafts of the sectors, connecting them with the disengaging gear, are 4½ inches in length. On the other end of one of the shafts a slotted lever is fixed, having an eye adjustable to the required radial length in connection with the governor. The shafts of the sectors are carried in continuous bearings, of cast iron, bolted to the dashpots, 7 inches long—the arms at one end and the sectors at the other end of the shafts.

The connection of the governor with the toothed sectors under the dash-pots for regulating the cut-off is made through a horizontal rod connected by a bell-crank to the lever of the governor. The rod is formed with Salt & Inglis' safety trip-gear, shown in figs. 601, constructed, like the

steam-valve rods, to disconnect the governor in case it breaks down. The rod, when freed from the governor, is pulled longitudinally by the action of
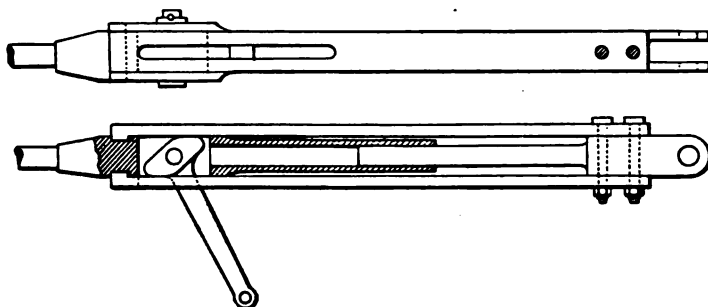
Figs. 601.—Hick: Salt & Inglis' Safety Trip-gear for the Governor. Scale 1/6th.

a weight on a bell-crank lever; and the effect of this movement is to shift the sectors and the pulling rods to the extreme positions, and to shut off all steam from the cylinder.
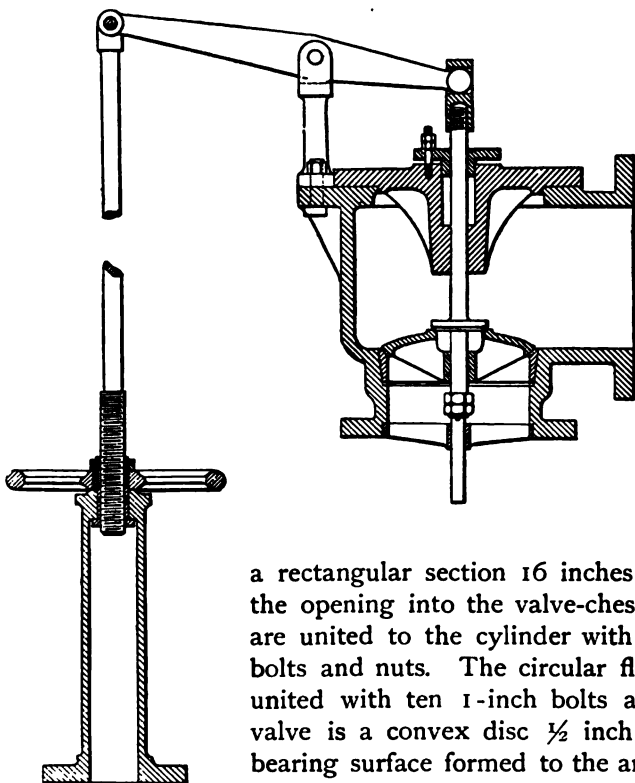
Fig. 602.—Hick: Stop-valve.
Scale 1/16th.

Steam is supplied to the cylinder from a cast-iron steam-pipe 12 inches in dia-meter, 1 inch thick, fitted with a 12-inch stop-valve above the cylinder, shown in section, fig. 602, from which the steam is conducted by branch pipes of the same diameter and thick-ness to each end of the cylinder, where they are flattened to a rectangular section 16 inches by 7 inches, forming the opening into the valve-chest at each end. They are united to the cylinder with sixteen ⅞-inch stud-bolts and nuts. The circular flanges of the pipe are united with ten 1-inch bolts and nuts. The stop-valve is a convex disc ½ inch thick, with a conical bearing surface formed to the angle 45°, bearing on a conical seat 12 inches in diameter. The crown of the disc is formed with a circular opening 4 inches in dia-meter, bevelled to form a seat for an auxiliary stop-valve, in order that steam may, at starting, be admitted by the 4-inch valve, which is allowed to rise from its seat 1 inch—the rise being

regulated by adjusting nuts—before the main valve begins to move.   Thus the steam may be easily and gradually admitted on starting the engine. The maximum total lift is 4 inches,—comprising 1 inch of lift of the auxiliary valve, and 3 inches of lift of the main valve.   The area of passage-way through the main valve for a lift of 3 inches is precisely equal to the sectional area of the 12-inch pipe, or 113.1 square inches.   The area of way through the 4-inch valve, likewise, is equal to the sectional area of a 4-inch pipe, or to one-ninth of that of the larger valve.   The case of the stop-valve is of cast iron, 1 inch thick, with flanges 1½ inches thick.   The cover is of cast iron, formed with a deep stuffing-box, which makes a long guide for the valve-spindle,—altogether, including the gland, 10 inches deep. The spindle is also guided at the bottom of the casing, below the valve-seat. The valve, valve-seat, guide, gland, and spindle are of brass.   The spindle is 1⅜ inches in diameter, reduced to 1⅛ inches beneath the nuts.   It is screwed at the upper end into a head formed with an opening to take the end of a lever through which the valve is opened from the floor of the engine-house.   The lever takes its fulcrum on a short pillar fastened to the top of the valve-casing.   The arms are 12 inches and 17¼ inches respec- tively in length, giving a leverage of nearly 1½ to 1.   The shorter arm is formed with a circular head, 2 inches in diameter, which plays in the slot- head of the spindle.   A 1½-inch rod depending from the other arm of the lever is screwed at the lower end, which is 2 inches in diameter, and works in a screwed brass bush 5½ inches deep.   The bush is secured to the top of a hollow cast-iron pillar, 2 feet high, 5 inches in diameter, and ½ inch thick, fastened to the floor with a flange-base 1¼ inches thick.   There is no throttle-valve on the en- gine, as the expansion- gear varies the admission by direct connection with the governor.

The steam is ex- hausted from each end of the cylinder downwards, into an 18-inch exhaust- pipe of cast iron, as shown in Plate VI. fig. 1, pass- ing horizontally under the cylinder to the condenser.
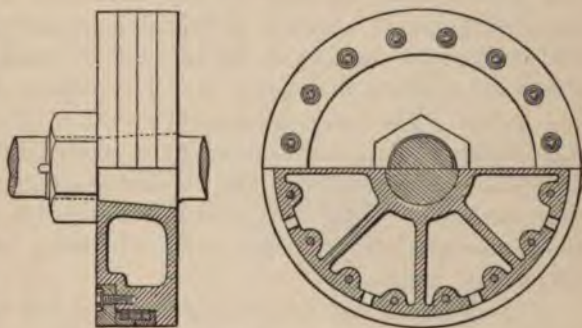
Figs. 603.—Hick: Piston.   Scale 1/24th.

The piston, shown in detail, figs. 603, is of cast iron, 40 inches in diameter and 10 inches thick.   It is hollow, and is formed with flat ex- ternal surfaces, being 1⅛ inches thick at the back and the front.   The body of the piston is cast in one piece, and a junk-ring 2½ inches thick and 5½ inches wide is let flush into the back, to which it is bolted with sixteen 1-inch screws on brass washers, at a pitch of 6½ inches.   The heads of the screws are let flush into the ring.   The packing is 5 inches wide, and consists of two cast-iron rings, each 2½ inches wide on the face,

formed with flanges, between and behind which a steel coil of three turns is lodged. The coil, forced by compression into the space behind the rings, exerts outward pressure on them and expands them against the inside of the cylinder. The coil is formed of a steel bar $7/8$ inch thick by $1\frac{3}{4}$ inches wide, tapered towards each end to a point, so as to pack into a space $3\frac{3}{4}$ inches wide, behind the rings. The recess formed by the body of the piston and the junk-rings is 5 inches wide and $1\frac{1}{2}$ inches deep. The centre is bored out conically to receive the piston-rod, round which the average thickness of metal of the piston is $1\frac{3}{4}$ inches. The centre is connected to the circumferential rim with eight radial ribs, 1 inch thick, which also unite the front and back faces of the piston, completing a box-casting of the strongest character.

The piston-rod, figs. 604, is of Bolton steel, 8 inches in diameter, and it is prolonged through the back cover of the cylinder, to a diameter of $7\frac{1}{2}$ inches. Within the piston the rod is formed conically to a diameter of $9\frac{1}{2}$ inches at the front and 8 inches at the back, showing a taper of $1\frac{1}{2}$ inches in 10 inches, or a little less than 1 in 7. The piston is secured on the rod by a nut 6 inches deep screwed up against the back, which is held in place by a cotter, 1 inch thick by $1\frac{1}{4}$ inches wide, rounded at the outer side, driven through the rod behind the nut. The piston-rod is let into the crosshead with a shoulder, being $6\frac{1}{2}$ inches in diameter at the shoulder, and tapered to 6 inches at the outer end of the crosshead. The centre of the cross-head is 12 inches long, and the taper of $\frac{1}{2}$ inch in 12 inches is at the rate of 1 in 24. The rod is secured in the crosshead by a nut 6 inches deep, retained by a transverse cotter through the rod, rounded at the outer side. The other end of the piston-rod is carried by a slipper-guide of cast iron, the sliding face of which is 18 inches long and 9 inches wide. It is bored, and is fixed on the end of the piston-rod, which is turned down to a diameter of 4 inches to receive it. The depth of the eye in the guide is $7\frac{1}{2}$ inches. The guide is fastened on the rod by a nut, 3 inches deep and $3\frac{1}{2}$ inches in diameter, secured by a small cotter through the end of the rod. The piston-rod is 12 feet $8\frac{1}{4}$ inches in length between the piston and the crosshead; 11 feet $11\frac{3}{4}$ inches between the nut behind the piston and the slipper-guide at the outer end. The total length of the rod over all is 28 feet $8\frac{3}{4}$ inches.

The crosshead, figs. 610, page 232, and shown in detail in figs. 604, is 4 feet $7\frac{1}{2}$ inches high, measured over the slipper-guides, being the distance between the guiding-plates of the frame. The guides are 39 inches long and 15 inches wide, flat, of cast iron, $1\frac{1}{4}$ inches thick in the sole at the centre, tapered in thickness to 1 inch at the edge, with a central eye $7\frac{1}{2}$ inches high, bored out to $5\frac{1}{2}$ inches in diameter, and stiffening flanges at the edges and in the centre-line. The centre of the crosshead is a cubical block of steel—a 12-inch cube—bored out to receive the piston, with two bearings, one on each side, $6\frac{1}{2}$ inches in diameter and $7\frac{1}{4}$ inches long, to take the connecting-rod; and two small bearings, $3\frac{1}{2}$ inches by $3\frac{1}{2}$ inches at the outside, to give motion to work the air-pump. On the upper and lower faces

of the cube, carriers are fixed by four 1¼-inch screw-bolts to each, turned to enter and occupy the eyes of the guides, and carry them to and fro. They are screwed to receive a pair of nuts to each carrier, by which the slippers can be adjusted to the distance apart of the guide or slide surfaces of the frame. The nuts are cylindrical externally, 10 inches in diameter, and are formed with notches ⅝ inch wide in the circumference to receive the key.

The main shaft or crank-shaft, figs. 605, is of Bolton steel, forged under a 25-ton hammer, and turned and polished. The bearings are 18 inches in diameter, of which the neck bearing,—next the crank, — is 27 inches long or 1½ diameters, and the outer bearing is 30 inches long or 1⅔ diameters. The bearings are 8 feet 3 inches apart, and the shaft between the bearings is 20 inches in diameter, enlarged to a diameter of 21 inches for a length of 3½ feet, to receive and carry the fly-wheel, which takes a bearing
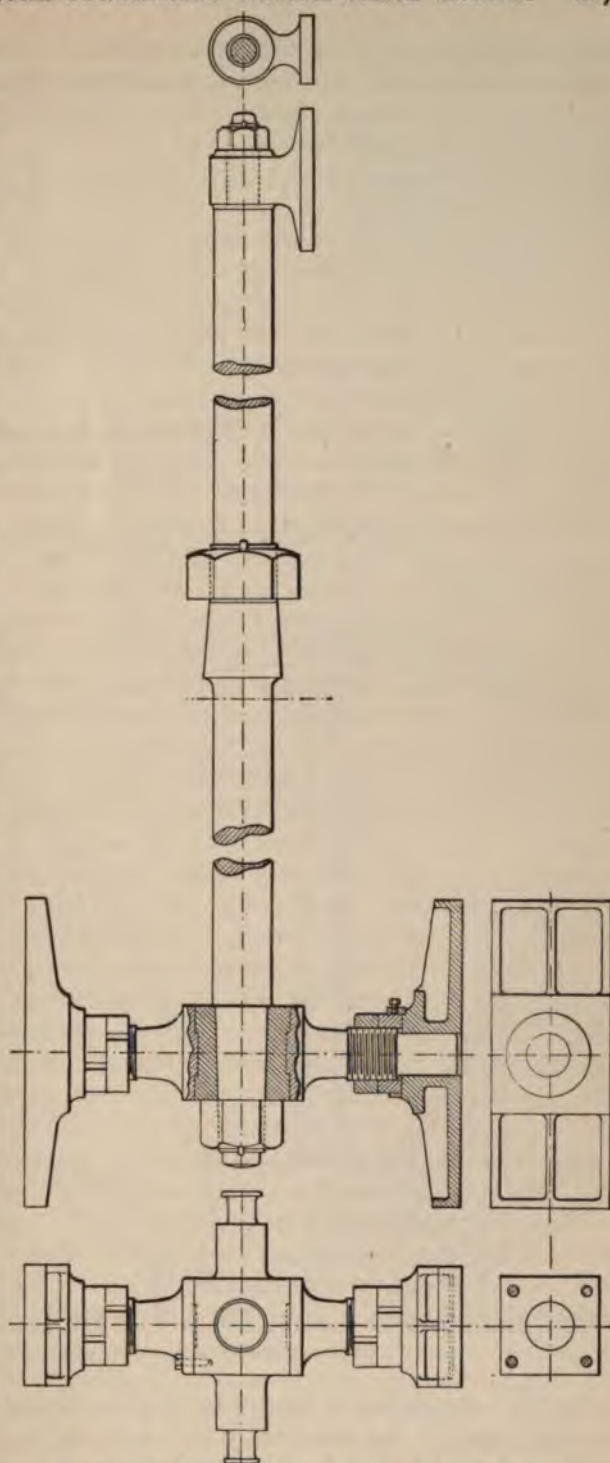
Figs. 604.—Hick: Piston-rod, Crosshead and Slides.   Scale 1/24th.

2 feet in length on the shaft. The fly-wheel is nearer the outer bearing than the neck bearing, and therefore the greater proportion of its weight is carried
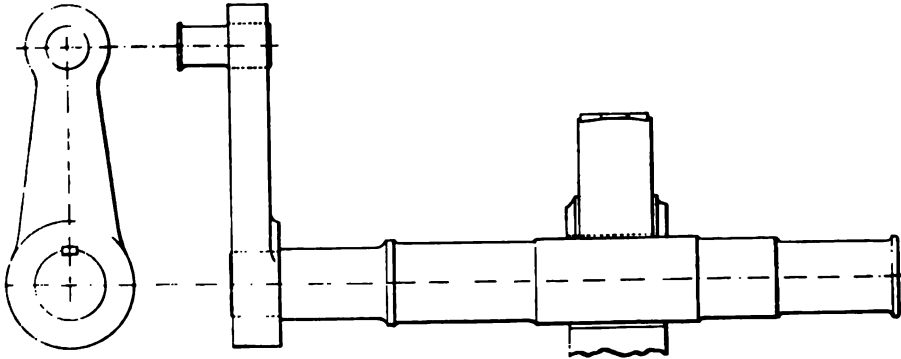
Figs. 605.—Hick: Crank-shaft and Crank. Scale 1/48th.

by the outer bearing, which is made 3 inches longer than the neck bearing, in compensation. The shaft is reduced to 17¾ inches in diameter, for a
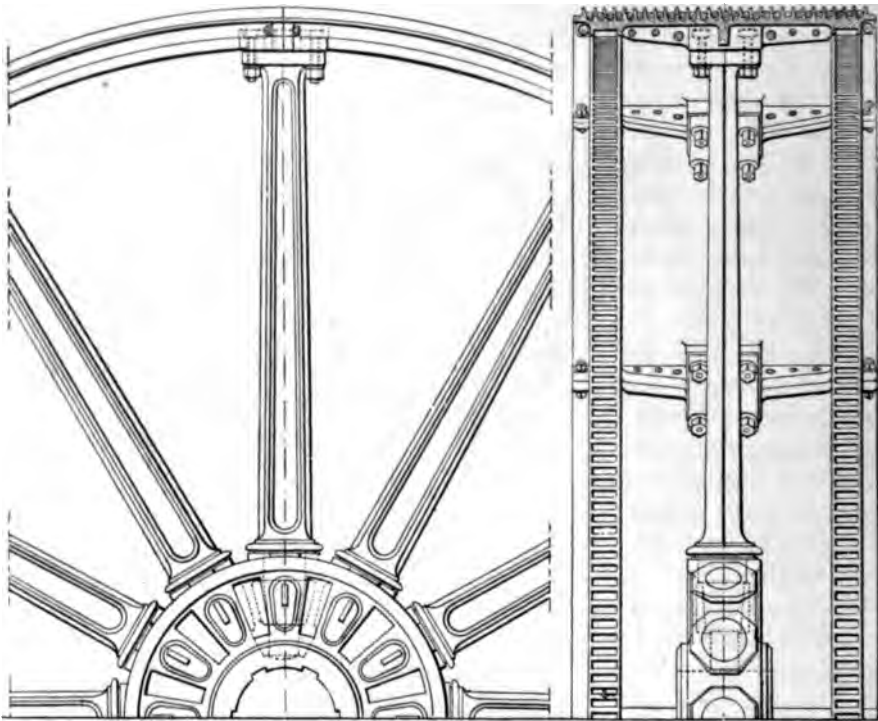
Figs. 606.—Hick: Rope-pulley Fly-wheel. Scale 1/48th.

length of 12⅛ inches, to receive the crank, offering a shoulder of ⅛ inch as an abutment for the crank when driven on to its place. A collar 2 inches wide and 20½ inches in diameter is formed on the shaft next the neck

bearing, being 2½ inches larger than the bearing. The back of the crank, at the other end of the bearing, keeps the shaft in position. The outer bearing is provided with a collar 2 inches wide and 20 inches in diameter at the end of the shaft, being 2 inches larger in diameter than the bearing. The length of the shaft over all is 14 feet 2⅛ inches. The crank is of wrought iron, turned, shaped, and polished. It is 5 feet long between centres, and 10 inches thick. The central eye is 12 inches long, and is 17¾ inches in diameter to fit the shaft, and 31½ inches in diameter outside, showing 6⅞ inches of thickness of metal round the shaft. The crank-pin is of steel, 10½ inches in diameter by 12 inches in length. It is enlarged to a diameter of 11 inches within the crank, and to 12 inches at the outer end, by 1¼ inches wide, to form the collar. It is shrunk into the crank, or, more correctly speaking, the head of the crank is shrunk on the pin. The head of the crank is 21 inches in diameter, showing 5 inches of thickness of metal round the crank-pin. The body of the crank is formed with straight sides, and tapers in width from 28½ inches as at the centre of the shaft to 12 inches as at the centre of the crank-pin.

The rope-pulley fly-wheel, figs. 606, is of cast iron, 30 feet in diameter, measured to the centres of the ropes, and 5 feet 11½ inches wide at the rim, which is grooved for 27 cotton ropes of 5 inches in circumference, or nearly 1⅝ inches in diameter, at 2½ inches of pitch. The grooves are shown in detail in fig. 607, with the rope in place. The rim is constructed
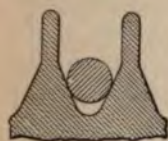
Fig. 607.—Hick: Detail of Rim of Rope-pulley. Scale 1/6th.

of 12 segments, with 12 arms. The segments are planed at the joints, and are bolted together with eight bolts and nuts, of which the two next the arms are 1¾ inches in diameter, and the others are 1½ inches. Each arm is secured with four 2-inch T-head bolts and nuts to the rim segments, two to each of two segments. The boss, nave, or centre, in section, figs. 608, is 6 feet ¼ inch in diameter, or 7 feet across the platforms or slightly raised plane surfaces on which the arms take their bearings. It is 18 inches wide at the rim, and 2 feet wide at the bearing on the shaft. Twelve sockets are bored out to receive the ends of the arms. The arms are formed approximately of H section, as in figs. 608, and measure 14 inches by 9 inches at the centre, and 9⅛ inches by 6¾ inches at the rim. They are

Figs. 608.—Hick: Arms of Fly-wheel. Scale 1/32d.

turned conically to fit the holes in the centre, tapering from 12 inches in diameter at the outer ends of the sockets to 7½ inches at the inner ends, in a total length of 2 feet 5 inches, as shown in figs. 608. Each arm is keyed into the centre with two cotters, each 24 inches long, 1 inch thick, tapering in width from 3¾ inches to 3¼ inches, or ½ inch in 24 inches, at the rate of 1 in 48. They are driven in one from each side of the nave reversely, and make up a width united of 6¾ inches. To join the rim the arm is expanded into a flat flange 21 inches by 18 inches and 4 inches thick, through which

Figs. 609.—Hick: Connecting-rod. Scale 1/24th.

the four bolts already named are passed. The opening at the centre is 25 inches in diameter, or 2 inches larger than the shaft. The wheel is fixed on the shaft with six keys 5 inches wide and 1⅝ inches thick, bearing on six flat seats formed on the shaft, with a taper of ⅛ inch to the foot.

The connecting-rod, figs. 609, is of hammered scrap iron, 28 feet in length, or 5.6 times the length of the crank. The ends are of the marine type, with caps and bolts, turned and polished, with phosphor-bronze steps. The steps or brasses are fitted and bored to the dimensions of the crank-pin, 10½ inches in diameter by 12 inches at one end, and with double ends to fit the crosshead bearings, each 6½ inches by 7 inches at the other end. At the crank end the butt and cap are 10 inches thick and 27 inches wide, and they are each 11 inches long, making, with packing plates 1½ inches thick, a total length of head of 23½ inches. The head thus made up is bored out to receive the brasses, which are 1⅜ inches thick and form up a cylinder 13¼ inches in diameter externally. The brasses have a flange at each side 1 inch thick to retain them in place, and making up the length of bearing for the crank-pin—12 inches. The cap and the butt, with the packing plates, are united by two 5-inch bolts and nuts. The heads of the bolts are 6¾ inches in diameter, and 3½ inches thick. The nuts are also

$3\frac{1}{2}$ inches thick; they are secured in place by a cotter through the end of the bolt. Each nut is turned down on the inner face, forming a fillet which enters a countersink in the cap, and so is firmly steadied against lateral stress or play. Each bolt is, for part of its length within the cap, reduced to a diameter of $4\frac{1}{4}$ inches; it is formed with a small stop-piece under the head, which enters a notch in the butt, to prevent the head from shifting round whilst the nut is being screwed up. The crosshead ends of the connecting-rod, which is forked, are constructed like the crank end. The butts and caps are 6 inches thick, and 20 inches wide; and are each $7\frac{1}{2}$ inches long, making together, with 1-inch packing-plates, a length of 16 inches. The brasses are 1 inch thick, with $\frac{1}{2}$-inch flanges; and the bolts are $3\frac{1}{4}$ inches in diameter, of which the heads are $4\frac{3}{4}$ inches in diameter, and, with the nuts, $2\frac{1}{2}$ inches thick. The nuts at both ends are pinched each by a set-screw inserted from one face of the cap—$\frac{3}{4}$-inch screws for the large end and $\frac{5}{8}$-inch screws for the small ends. The heads of the screws are shown in the lower figure 609. The length of the body of the rod between the butts is 26 feet $4\frac{1}{4}$ inches. It is circular in section, and is 9 inches in diameter at the crank end, 8 inches at the crosshead end, and gradually swelled to 12 inches in diameter at the middle of its length.

The frame, figs. 2 and 3, Plate VI., and in figs. 610, 611, and 612, is of cast iron, $1\frac{3}{4}$ inches in thickness, of box-girder section. It has a total length of 40 feet $2\frac{1}{2}$ inches, measured from the end of the cylinder to the outer edge of the main-shaft pedestal; and is cast in two pieces bolted together and to the cylinder. The first piece, 14 feet 9 inches long, figs. 610, is arranged to carry the slides for the crosshead, which are 4 feet $7\frac{1}{2}$ inches apart. The slides, upper and lower, are of cast iron, $1\frac{3}{4}$ inches thick, with flat faces, 15 inches wide, having lateral flanges rising $1\frac{1}{4}$ inches high, to direct the slipper-guides. The lower slide-plate, on which the stress of guiding and sustaining and resisting the weight, and the oblique action of the connecting-rod, chiefly falls, is solidly supported on the base of the guide-piece; and the upper slide is fastened to the overhung head of the casting. The slide-surfaces are only 12 feet 11 inches long, so that the sum of the travel of the crosshead guides, 10 feet, and their length, 3 feet 3 inches —together 13 feet 3 inches—exceeds the length of the slide-surface by 4 inches, or 2 inches at each end; and the guides push off any dirt or refuse at each end of the stroke that may collect on the faces of the slides. The slides are each fixed to their seats by eighteen $\frac{7}{8}$-inch bolts at 18 inches of pitch, screwed through the side flanges into the metal, with cheese-heads sunk flush, as in figs. 610. The girder-piece is bolted to the end of the cylinder by a circular flange 5 feet $1\frac{1}{2}$ inches in diameter, $2\frac{1}{2}$ inches thick, with twenty-two $1\frac{1}{2}$-inch bolts, pitched at about $7^{7}/_{16}$ inches. At the outer end it is strengthened by a bow-piece or tie, fitted to it with joggled surfaces, by which the upper projecting part is bound to the base, as shown in figs. 610. The bow is bolted to the frame by four $1\frac{3}{4}$-inch bolts at the base, and two bolts at the top. Thus is completed the approximately elliptical figure of the slide-framing, where also the casting is made with a broad flat
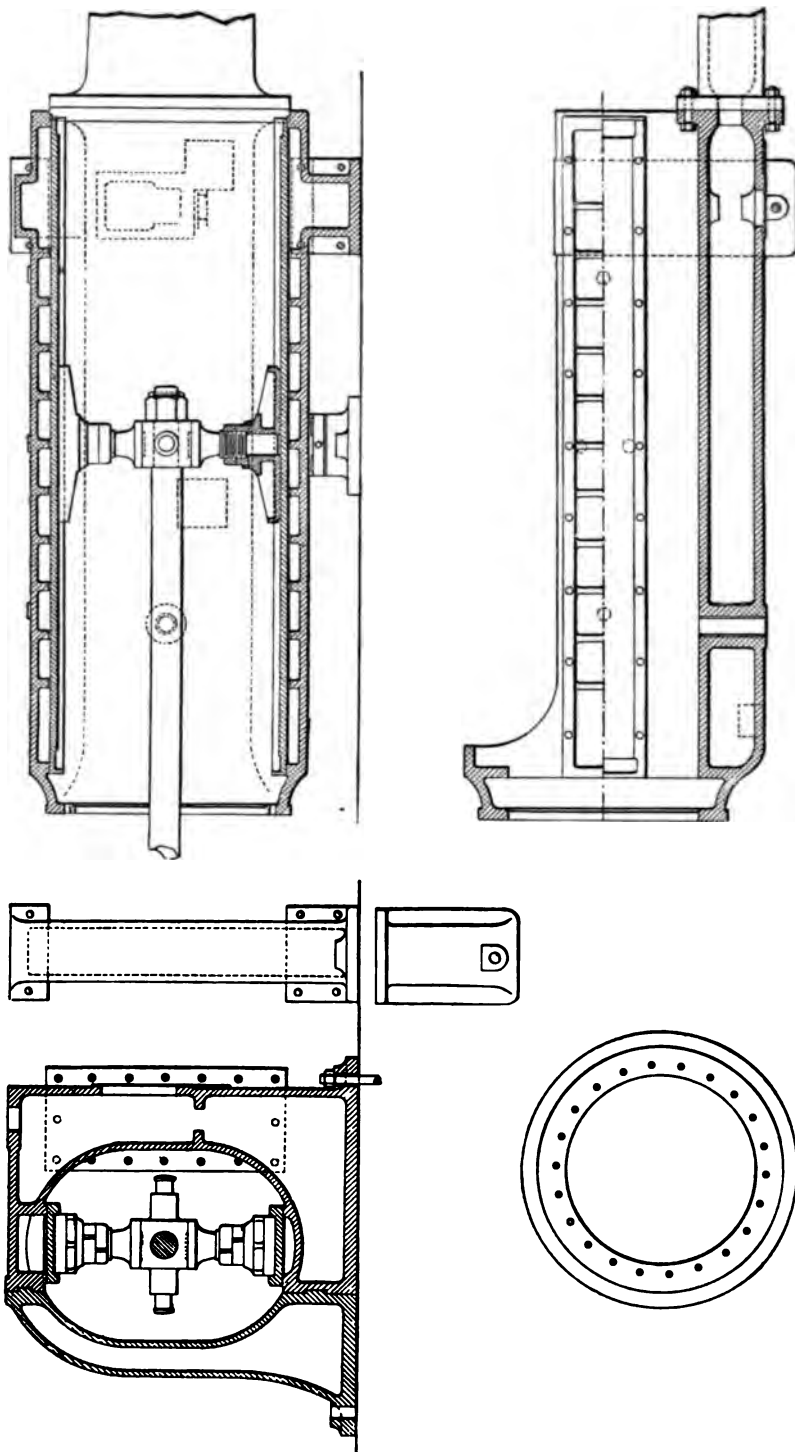
Fig. 610.—Hick: Frame.   Scale 1/48th.

t, which is supplemented by the base of the bow-piece, and makes
nited base or sole 8 feet in width, transversely to the frame, and 2 feet
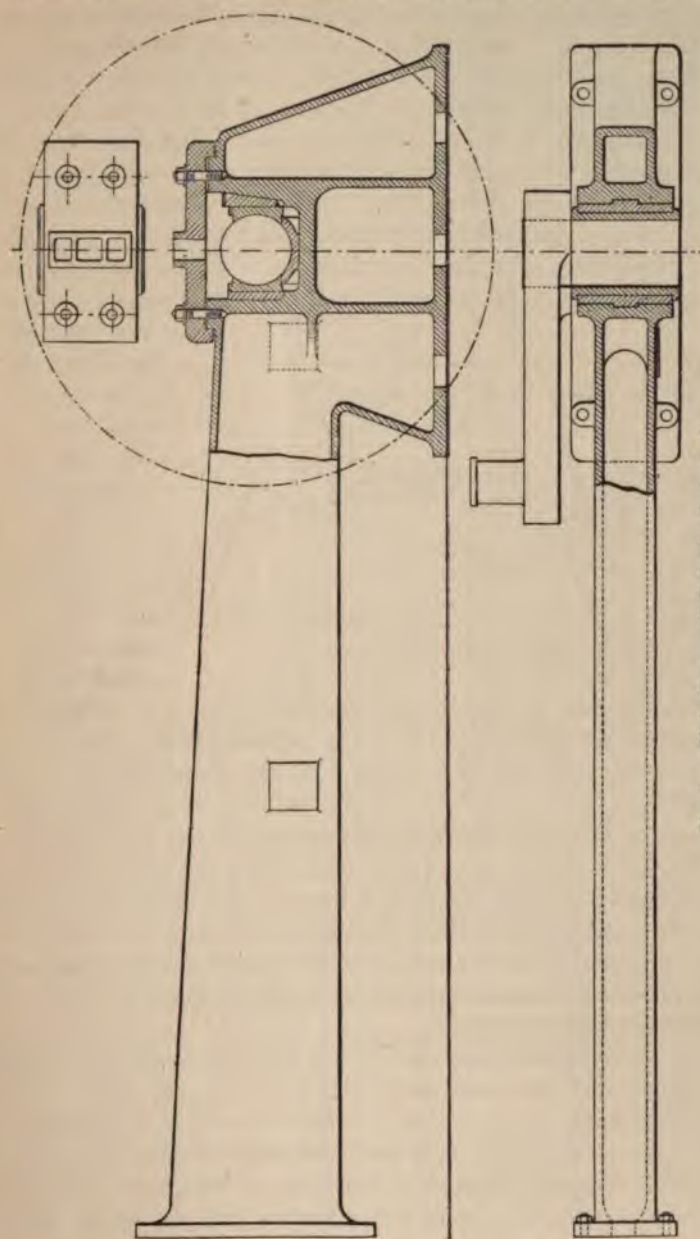
Figs. 611.—Hick: Frame with Pedestal.   Scale 1/48th.

oad longitudinally, 3 inches in thickness.   For the holes for two 2½-inch
lding-down bolts the sole is increased to 6 inches in thickness.

The second piece of the frame, figs. 611, is 25 feet 5½ inches long, and
nprises a plain box-girder, rectangular in section, and the pedestal for the

main shaft. The girder portion is 15 inches wide, 42 inches deep at the junction with the other casting, tapering down to 32 inches deep at the pedestal. The pedestal, figs. 611 and 612, is a hollow structure, on a base or sole 9 feet long by 2 feet 3 inches wide, and 3 inches thick, standing 4 feet high to the centre of the bearing. The brasses are of phosphor-bronze, bored out to 18 inches, the diameter of the journal, and 27 inches in length. They are in three pieces, two sides and a bottom piece, of which the two side pieces are provided for horizontal adjustment, and are 1¾ inches thick on the centre-line. A square seating is formed in the pedestal for the reception of the brasses, with cast-iron packing plates, joggled to the seating, of which the outer one is wedge-form, for horizontal adjustment. It is allowed to bottom—that is, to settle down as far as it
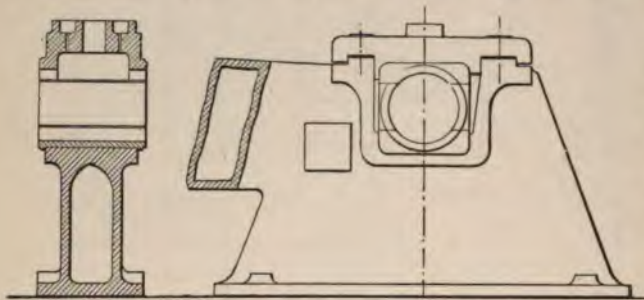
Figs. 612.—Hick: Pedestal. Scale 1/48th.

can go. When adjustment is needed a small strip is cut off the thin end of the wedge, and it is bolted hard down under the cover. The wedge-piece is occasionally made adjustable by means of screws,—a method which, under careful management, is the more convenient in use. This means of longitudinal adjustment for wear tends to shorten the distance between the shaft and the cylinder in keeping with the shortening of the connecting-rod by wear. The bottom of the seating is 4 inches thick, and the sides are 3 inches thick, with extensions to the base-plate, 2 inches thick. The cap is a shell cap, of cast iron. It is 5 inches thick in the top, with side flanges, checked upon and binding the sides of the seating, to which it is fastened by four 2-inch stud-bolts and nuts.

The two pieces of girder-frame are bolted together with flanges 26 inches wide, from outside to outside, 5 feet 5 inches deep, and 3½ inches thick, and sixteen 1¾-inch bolts and nuts.

There is a subordinate member of the frame behind the cylinder—the slide for supporting the outer end of the piston-rod. It is of cast iron, hollow and rectangular in section, 12 inches wide, 7½ inches deep, and 1 inch in thickness of metal. It is bordered with a rising flange at each side, 1 inch high. Between the flanges, 9 inches apart, the guide for the piston-rod slides. The sliding surface is 11 feet 4 inches long, whilst the total length of traverse covered by the guide—the length of stroke plus the length of the guide—is (10 feet + 1 foot 6 inches =) 11 feet 6 inches. This is 2 inches in excess of the length of the slide, and provides an overhang of 1 inch at each end of the stroke, helping to equalize wear, and to clear the slide of dirt. The slide is bolted to the stuffing-box of the back cylinder-cover with two

1½-inch bolts and nuts, and is supported by a cast-iron stool near the outer end.

The under sides of the supports for the framing are planed, and are bedded direct on the stone surface of the foundation.

The total length of the engine framing, from the end of the back slide to the end of the base of the pedestal, amounts to 65 feet 3¾ inches; and the total length occupied by the whole engine, including the fly-wheel, is 75 feet 11¾ inches—say 76 feet.

The steam is exhausted from the cylinder through a cast-iron pipe 18 inches in diameter, 1 inch thick, with cement flange-joints, into the condenser, figs. 613, of cast iron, placed upright in a recess formed in the foundation, beneath the framing. It is cylindrical, 3 feet 5 inches in diameter inside, 6 feet 4 inches high, and 1 inch in thickness, having an 18-inch circular opening in the top corresponding to the size of the exhaust-pipe, for the admission of the exhaust steam; and a circular opening in the bottom, 2 feet
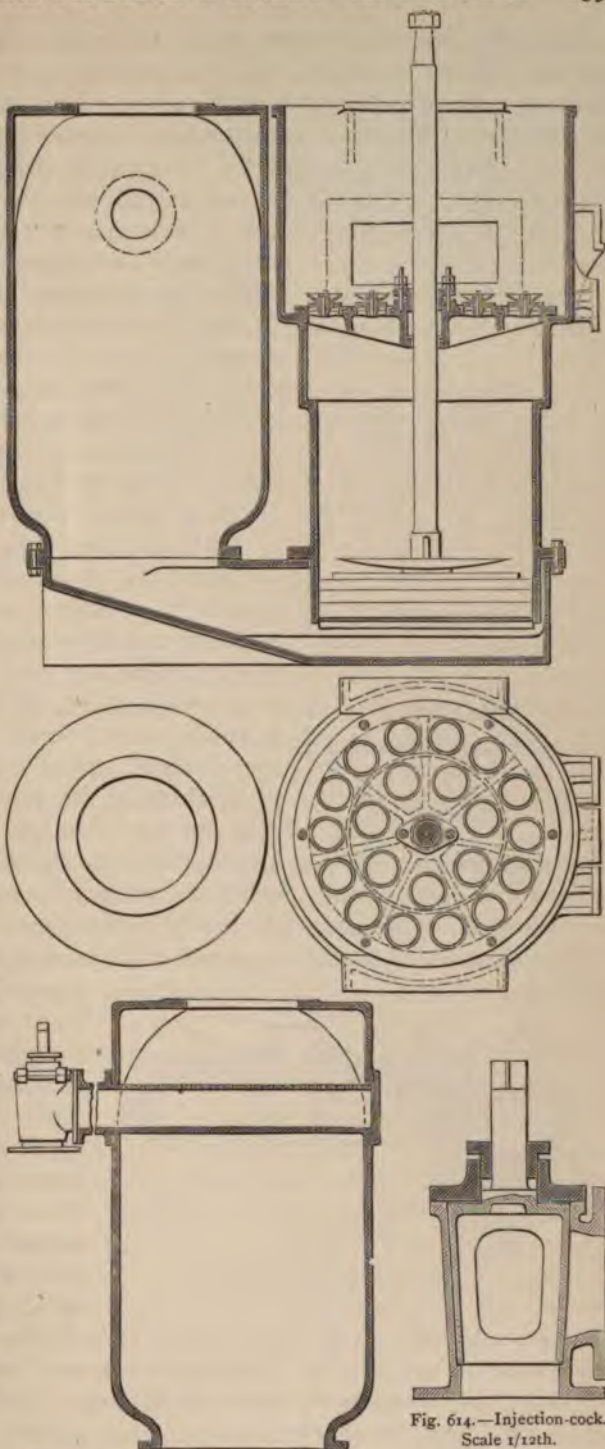
Figs. 613.—Hick: Condenser and Air-pump.
Scale 1/32d.

Fig. 614.—Injection-cock.
Scale 1/12th.

4 inches in diameter, for the escape of condensed steam, condensing water, and air into the air-pump. The injection-cock, fig. 614, shown in place in the lowest figure 613, for the supply of condensing water, is of brass, 7 inches in diameter. The plug is 10 inches long, having 1 inch of taper, and is ⅜ inch
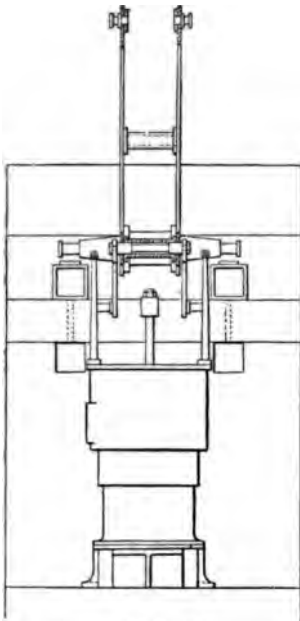
Fig. 615.—Hick: Air-pump.
Scale 1/80th.

thick. The injection-pipe is of cast iron, 6 inches in diameter, ½ inch thick. The pipe crosses the condenser at a level 14½ inches clear below the top. It is perforated with 300 half-inch holes drilled in the upper part for the upward projection of the condensing water in numerous streams, to meet with and condense the steam entering downwards. The usual quantity of condensing water supplied is at the rate of from 50 to 60 gallons per indicator horse-power per hour, and the vacuum obtained is equivalent to about 28 inches of mercury.

The air-pump, figs. 613 and 615, is placed alongside the condenser, both resting on and bolted to a hollow casting, which forms the communication between the pump and the condenser. The air-pump is of 1-inch cast iron. It is single-acting, 36 inches in diameter, with a stroke of 2½ feet. The bucket, with rings and follower, are of brass, of a total thickness of 8 inches. The valve, on the upper side of the bucket, has a disc of india-rubber, 31 inches in diameter and 1 inch thick; controlled by a brass disc, which admits of a lift of about 2 inches at the circumference of the valve, offering a maximum of 195 square inches of outflow area. The bucket-rod is of iron, 3½ inches in diameter; except in the bucket, within which it is conical,
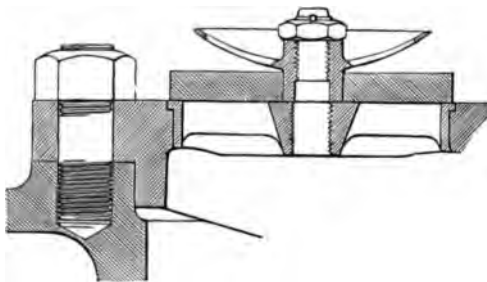
Fig. 616.—Hick: Air-pump Valve. Scale 1/4th.

tapering from 5 inches in diameter at the lower side of the bucket to 4 inches at the upper side. It is secured by a cotter 1 inch thick, above the bucket. The upper part of the barrel is enlarged to a diameter of 39 inches and is closed by a cover of cast iron, which is fixed to it by six 1-inch stud-bolts and nuts, perforated for twenty-one delivery-openings. The openings are 5⁷/₁₆ inches in diameter, fitted each with an india-rubber disc, 6 inches in diameter and ⅝ inch thick. One of these disc-openings is shown in fig. 616. Each disc when fully raised gives an ¹¹/₁₆-inch opening, making 11⅝ square inches; or for 21 discs 244 square inches of united opening for upward flow, or 25 per cent

greater than the passage-way by the bucket-valve. The up-flowing water is received into the upper part of the air-pump, or hot-well, which is 4 feet in diameter, and runs off thence through a rectangular opening 2 feet wide, 9 inches high, having the area 216 square inches—a little more than one-fifth of the sectional area of the pump. There is no foot-valve.

The base on which the condenser and the air-pump rest, is of cast iron 1 inch thick. It is 15 inches high inside, and is formed with a sloping bottom falling from the condenser, so as to deliver the water and air to the air-pump. The pump is projected downwards into the base to within 6 inches off the bottom of it. All the joints of the condenser and the air-pump are metal-to-metal, and pipe-flanges are faced across. The joints are cemented with a mixture of red-lead, boiled oil, and fine iron filings.

The castings of the condenser, air-pump and base, are tested with a hydraulic pressure to 30 lbs. per square inch.

The air-pump is worked off the main crosshead by means of a bell-crank lever, Plate VI. and fig. 615, of which the arms are 8 feet and 2 feet in length between centres, reducing the length of the stroke in the ratio of 4 to 1, or from 10 feet to 2½ feet. The lever is constructed of two iron plates, 1¼ inches thick, spaced suitably apart to take the connecting links from the ends of the crosshead-pin. They are fastened together by the gudgeon, which is 9 inches in diameter at the middle, and is keyed into a cast-iron centre-piece between the plates and riveted to them. The gudgeon is reduced towards the extreme bearings, the journals being 5 inches in diameter and 7½ inches long, and 5½ feet apart from centre to centre. The bearings are supported by cast-iron box-girders 15 inches square, built at the ends into the brickwork of the foundation, and fastened by short holding-down bolts with plates. The longer arms are also fastened together at mid-length by a cast-iron thimble or distance-piece, with a through-bolt and nut. The air-pump rod is fitted with a crosshead and slides, which work between upright guide-bars fastened to the top of the hot-well. The motion of the crank-arm is communicated to the crosshead by means of two links.

The feed-pump, shown in the general view, Plate VI., and in detail, figs. 617, is bolted to the side of the hot-well, with which it has two communications on one level, one being the suction-pipe, and the other the discharge-pipe from the relief-valve, 4 inches in diameter. The pump being at a lower level than the hot-well, the water flows into it by gravitation, and it is spared the task of raising the hot water at the suction side. Hence such pumps are known as hot-water pumps. The delivery-pipe, also 4 inches in diameter, conducts the water from the upper part of the pump to the boiler, and is fitted with an air-vessel near to the pump. The plunger is of brass, 5 inches in diameter, ½ inch thick, with a stroke of 21 inches, being linked to and worked by a 19-inch arm off the back of the bell-crank. The casing of the pump is of cast iron, 6½ inches in diameter inside, giving ¾ inch clearance round the plunger; and it is 1 inch in thickness. The link from the arm takes a cross-pin 1½ inches in

diameter, let into a block of wrought iron fitted into the bottom of the plunger, and fastened to it by a screw and nut. The end of the link takes a bearing, for the down or delivery stroke of the plunger, on the iron block,
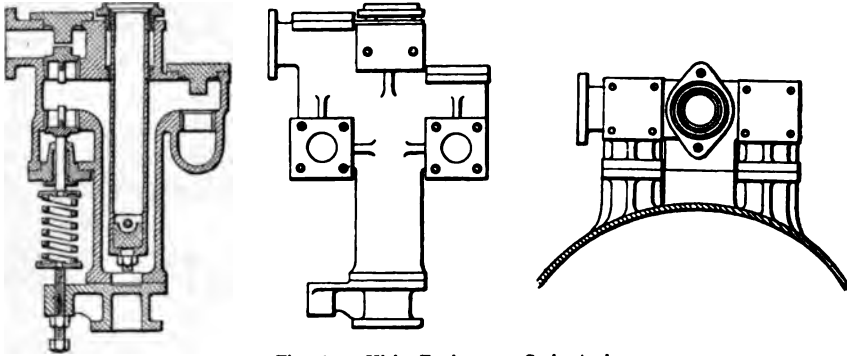
Figs. 617.—Hick: Feed-pump. Scale 1/24th.

the upper side of which is formed with a circular excavation to receive the link and take the thrust: the function of the pin being to draw the plunger for the upward or suction stroke. There are three brass valves in brass seats, each 4 inches in diameter, for the suction, relief, and delivery re-
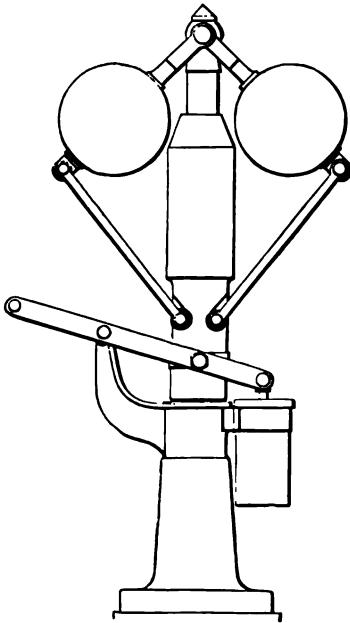
Fig. 618.—Hick: Governor. Scale 1/14th.
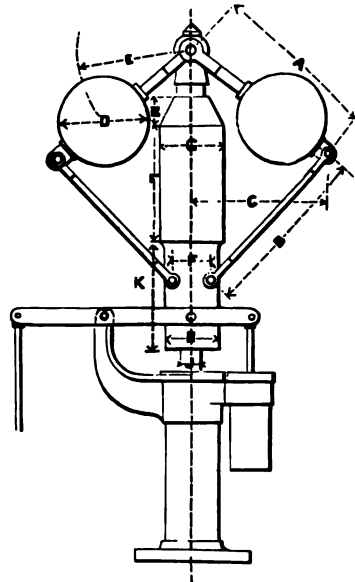
Fig. 619.—Hick: Governor, with Reference Letters.

spectively. They have mitre seatings, ½ inch in width, with three guide-wings; and the lift of the suction and delivery valves is limited to ½ inch. The relief-valve is closed by a helical spring of ¾-inch square steel, 4½ inches in diameter, under a compression of 10 lbs. per square inch

above the pressure in the boiler: adjustable by a 1¼-inch set-screw,—the spindle of the valve passing through a stuffing-box to take the pressure.

The governor, fig. 618, is on the system of two revolving balls, of cast iron, suspended from points in the centre-line of the axis, and loaded by a central weight. The balls are 8 inches in diameter. The action of the governor is steadied by a dashpot, about 3½ inches in diameter, in order to prevent too rapid changes, and consequent fluctuations in the position of the governor, by the disturbing action of the valve-gear or of sudden variations of load. For this purpose, it is filled with oil and is occupied by a piston, which is perforated with two ⅛-inch holes, through which the oil must pass, to admit of the vertical movements of the piston. The restriction of circulation thus effected operates in braking the governor. The limits of admission, under the control of the governor, are from 75 per cent of the stroke down to no admission at all.

Three sizes of governor are employed by Messrs. Hick, Hargreaves, & Co., for steam engines constructed by them, indicating from 1500 horse-power to 50 horse-power. They have balls respectively 8 inches, 6 inches, and 4 inches in diameter, and make 126 turns, 158 turns, and 218 turns per minute. The annexed tablet contains the leading dimensions of the governors, with reference letters to the figure 619:—

Size.	A.	B.	C.	D.	E.	F.	G.	H.	J.	K.	L.	M.	Turns per Minute.
	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.	
Large....	16	16	12⅜	8	10½	3⅜	6	4¾	2¼	10¼	11	2¾	126
Medium	12	12	9¼	6	7⅞	2⅝	5	4	1⅞	7⅞	8⅛	1¾	158
Small....	8	8	6¼	4	5¼	2	4	3⅛	1⅜	6	5	1	218

The weights of the principal pieces of the engine are as follows:—

	Tons.	Cwts.	Qrs.	Lbs.		Per cent.
Cylinder...............................	12	19	1	2	or	9.2
Piston................................	0	18	0	18	,,	0.6
Piston-rod	2	1	0	2	,,	1.4
Connecting-rod	4	13	3	16	,,	3.3
Main shaft............................	6	6	0	0	,,	4.5
Crank and pin........................	2	5	2	2	,,	1.6
Rope fly-wheel.......................	54	12	0	5	,,	39.0
Frame................................	23	11	3	14	,,	17.0
Condenser and air-pump..............	4	14	3	24	,,	3.4
Levers and gear for working air-pump.........	2	1	0	0	,,	1.5
Steam-pipes and other pipes, valves, governor, &c., not included in the separate weights above given; holding-down bolts, washers, and plates, &c., say............................	25	16	3	1	,,	18.5
Total...........................	140	0	0	0	,,	100.0

The plan of the foundation, which is shown in elevation in Plate VI., fig. 1, is given in the annexed figure, 620, of the engine-house in plan. The foun-

dation is 20 feet deep, and contains about 430 cubic yards of solid masonry, consisting of top and bottom courses of stone, with brickwork laid in cement. The engine-room is 76 feet in length and 23½ feet wide. The foundation under the cylinder is 12 feet wide; and, under the main shaft, it is 10¼ feet wide. The right-hand end of the engine-room opens into the rope-chamber beyond.

The price of this engine, at current rates, is, say, £4000. The cost for the foundation, say 430 cubic yards at the rate of 36s. per cubic yard, is about £774.

			Per cent.
Engine, complete,...	£4000	or	84
Foundation, ...	774	„	16
Total,.........	£4774	„	100

Reduced samples of indicator diagrams taken from the engine when at its ordinary work are shown in figs. 621, when the working pressure in the boilers was 55 lbs. per square inch, and the engine was making 42 revolutions, or 840 feet of piston, per minute. The initial pressure in the cylinder was 46½ lbs. and 45 lbs. above the atmosphere, the steam was cut off at about 25 per cent of the stroke, when it was wiredrawn to 43¾ lbs. and 42½ lbs. respectively, dropping 2¾ lbs. and 2½ lbs. in pressure, by wiredrawing. The final pressures by expansion, assumed by the eye as for the end of the stroke, are respectively 2 lbs. and 3 lbs. below the atmospheric pressure; adding the clearance, 1½ per cent of the stroke, to the period of admission, the total volume of steam for expansion is 26½ per cent, and 101½ per cent on the completion of the stroke—in the ratio of
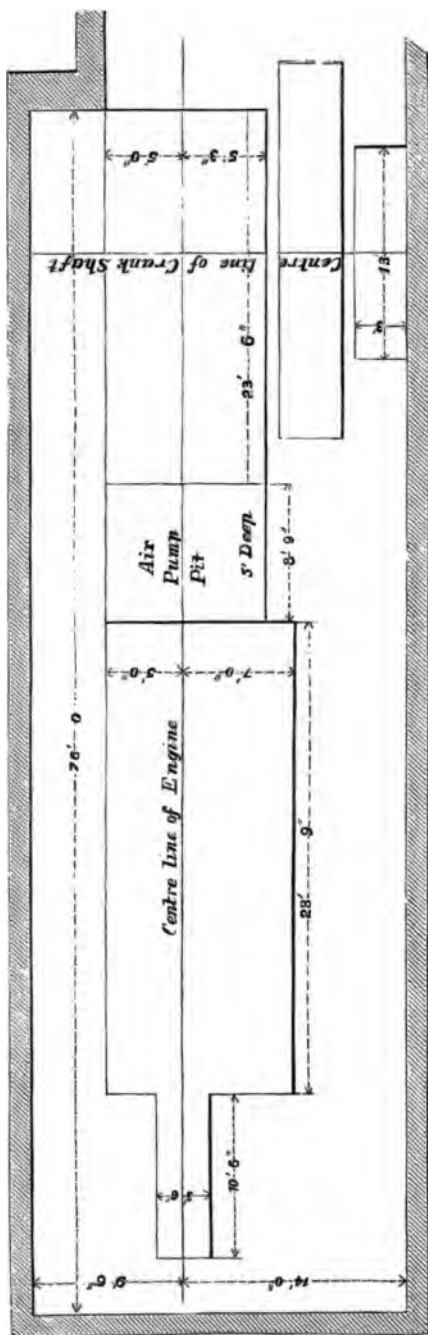
Fig. 620.—Hick: Plan of Foundation. Scale 1/144th.

1 to 3.83. The corresponding mean ratio of the absolute pressures, supposing the atmospheric pressure equal to 14.7 lbs. per square inch, is as ($44\frac{3}{8}$ lbs. + 14.7 lbs. =) 59.1 lbs. to (2.5 + 14.7 =) 17.2 lbs., or as 3.44 to 1. Thus, the pressures beginning and after expansion are nearly in the ratio of the volumes inversely. The final pressure due to the ratio of the volumes inversely would be (59.1 lbs. ÷ 3.83 =) 15.4 lbs., or 1.8 lbs. less than the actual pressure. The relative weights of sensible steam at the beginning and the end of the expansion are as the products of the densities or weights per cubic foot by the volumes, or as (.1405 lb. × 1) is to (.0440 lb. × 3.83), or as .1405 to .1685. The difference of these values is .0280, which is 16.6 per cent of the second value—pointing to an initial condensation of 16.6 per cent of the steam admitted into
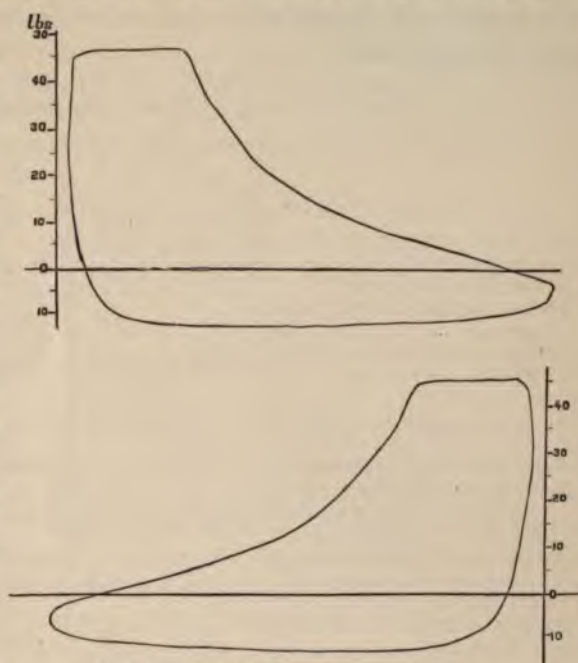
Figs. 621.—Hick's Engine: Indicator Diagrams.

the cylinder. This percentage is only about two-thirds of the percentage of condensation given in table No. 101, vol. i. p. 474, for unprotected cylinders.

This engine, with another working at the establishment of Messrs. Illingworth & Sons, constructed by the same manufacturers, were tested by Mr. Niel M'Dougall in 1882.[1] The neighbouring engine, constructed in 1871, was horizontal, with Corliss valve-gear, and in other respects like the engine already described, except that the cylinder was $38\frac{1}{4}$ inches in diameter, with a stroke of 5 feet. The clearance for the steam-valves was 2.39 per cent of the capacity of the cylinder. The steam-pipe was 9 inches in diameter, and the exhaust-pipe was 14 inches. The air-pump was 28 inches in diameter, with a stroke of $2\frac{1}{2}$ feet. The two engines were supplied from the same boilers; the steam supplied to each was not separately measured. The boilers were double-flued, 30 feet long and 8 feet in diameter, with furnace-tubes 3 feet $1\frac{1}{2}$ inches in diameter, crossed by four cylindrical water-tubes in each flue. They were constructed in 1882. They were worked in connection with two Green's economizers, one of which, nine years old, had 256 pipes; and the other, seventeen years old,

[1] *Trials of Steam Engines*, conducted under the direction of Niel M'Dougall, M.I.C.E., for the Boiler Insurance and Steam Power Company. 1882.

had 252 pipes. The total area of fire-grate was 131¼ square feet, and that of the heating surface was 3810 square feet, or 29 times the grate-area. The heating surface of the economizers was 5376 square feet, making, with the surface of the boilers, a total of 9186 square feet, or 70 times the grate-area. The total steam-space for the usual working level of water in the boilers was 1700 cubic feet.

Results of Trials of Messrs. Illingworth's Engines.

	First Day.		Second Day.		Third Day.	
	1st Engine.	2d Engine.	1st Engine.	2d Engine.	1st Engine.	2d Engine.
Duration of trial..................	6h. 47m.	6h. 47m.	7h. 47m.	7h. 47m.	2h. 17m.	2h. 17m.
Revolutions per minute	42.7	42.4	41.16	42.1	42.2	43.0
Speed of piston in feet per minute	854	424	823	421	844	430
Average indicator horse-power	896	429.6	916.8	411.8	919.5	425
Combined do. do. ...	1325.6		1328.6		1344.5	
Average sensible pressure in boilers	70.3 lbs.		69.7 lbs.		59 lbs.	
Average barometer pressure..	29.1 ins.		29.2 ins.		29.5 ins.	
Average initial pressure in cylinders, in lbs. per sq. in. above the atmosphere	59.4 lbs.	61.7 lbs.	60.5 lbs.	60.25 lbs.	53.5 lbs.	50.35 lbs.
Average period of admission, shown by the published indicator diagrams	11.9%	12.7%	13.7%	12.3%	17.5%	15.2%
Average actual ratio of expansion	6.61	6.74	6.47	6.8	5.09	5.4
Coal, description	Engine Burgy.		Engine Burgy.		Engine Burgy.	
Do. consumed per hour......	24.57 cwts.		25.54 cwts.		28.80 cwts.	
Do. do. per sq. foot of grate	20.96 lbs.		21.79 lbs.		24.56 lbs.	
Do. do. per indicator horse-power per hour ...	2.076 "		2.153 "		2.41 "	
Ash, per cent	14.9 per cent.		12.8 per cent.		—	
Temperature of feed-water....	110° F.		110° F.		118° F.	
Water evaporated per hour...	23990 lbs. / 387.56 cu. ft.		24379 lbs. / 393.86 cu. ft.		25489 lbs. / 411.80 cu. ft.	
Condensation-water collected from main steam-pipes per ho.	92 lbs. / 1.46 cu. ft.		179 lbs. / 2.94 cu. ft.		181 lbs. / 2.97 cu. ft.	
Do. per cent of total water evaporated per hour	0.38 per cent.		0.74 per cent.		0.71 per cent.	
Water passed through the engine per hour	23898 lbs. / 386.10 cu. ft.		24200 lbs. / 390.92 cu. ft.		25308 lbs. / 408.83 cu. ft.	
Water per indicator horse-power per hour	18.02 lbs.		18.21 lbs.		18.82 lbs.	
Do. do. calculated from the indicator diagrams.....	15.09 lbs.	15.30 lbs.	15.22 lbs.	15.88 lbs.	16.30 lbs.	16.67 lbs.
Percentage of steam proved by the indicator	84.09 per cent.		84.67 per cent.		87.32 per cent.	
Water evaporated per lb. of coal	8.71 lbs.		8.52 lbs.		7.9 lbs.	
Equivalent evaporation from 100° F. at 212° F.............	8.89 "		8.69 "		7.98 "	
Do. do. from and at 212° F.	9.93 "		9.71 "		8.93 "	

The foregoing results of the trials are selected from Mr. M‘Dougall's report. They are the average results of all the indicator diagrams that were taken. The average actual ratios of expansion are calculated for the whole stroke of the piston, clearance included. The indicator diagrams published in the report were selected as the most nearly representing the average working of the engines during the trial. They resemble those above given, figs. 621. For calculating the weight of water from the indicator diagram, the terminal pressures, as representing the greatest weight of steam for the stroke, were adopted. The average periods of admission have been interpolated by the author.

A horizontal condensing Corliss engine, of construction similar to that of the engine just described, by the same manufacturers, was erected in 1883, at the Eagley Mill, near Bolton, the property of Messrs. Chadwick Brothers. The cylinder and valve-gear, and part of the frame of this engine, are shown in figs. 622 and 623. The cylinder is 52 inches in diameter, with a stroke of 6 feet, and it makes 60 turns, or 720 feet of piston, per minute. The crank-shaft, of Whitworth's fluid compressed steel, is 20 inches in diameter at the journals, and these are 30 inches in length. The shaft is 22 inches in dia-meter in the fly-wheel. The crank is of wrought iron. The crank-pin is 12 inches in diameter; it is a hollow forging of compressed steel. The connecting-rod is 17 ½ feet long, or 5.83 times the length of the crank; 10 inches in diameter at the ends, swelled to 17 inches at the middle. The crosshead is of forged steel; so also is the piston-rod, which is 9 inches in diameter. The forgings were made by the Bolton Iron & Steel Company. The air-pump is 36 inches in diameter, with a stroke of 30 inches. The bucket is fitted with 18 india-rubber discs, instead of one rubber disc, as in the other engine. The delivery-valve has 21 discs. The condenser has a capacity three-fourths of that of the cylinder. The piston is packed with Mather & Platt's coil. The fly-wheel is 24 feet in diameter, and 11 feet 8 inches wide at the rim, turned on the face. It is constructed with two separate naves and sets of arms; and the sides are cased with wood. The weight of the wheel is 68 tons. The power is taken off by means of three cotton driving bands.

Corliss valves are employed with slip-gear; but the valve-gear is entirely different from that of Messrs. Illingworth's engines, above noticed. One object had in view in devising this gear was the prompt opening of the valve to its full extent, or nearly so, at a very early period of the stroke. The steam-ports are fully open at $1/10$th of the stroke. The valves are worked from a horizontal shaft parallel to the axis of the cylinder, on the same level, driven by means of bevel wheels from the main shaft. The end of each steam-valve arm is engaged in a slot formed in an upright rod, which is moved vertically by the action of a cam on the shaft to open the port for steam. For this purpose the cam acts upon a horizontal cast-iron bracket with a sleeve, which slides on the upright rod, and is guided by it. At the upper part of the bracket, a lever piece is pinned to it, into which a steel engaging piece is notched; and this piece engages with a corresponding steel
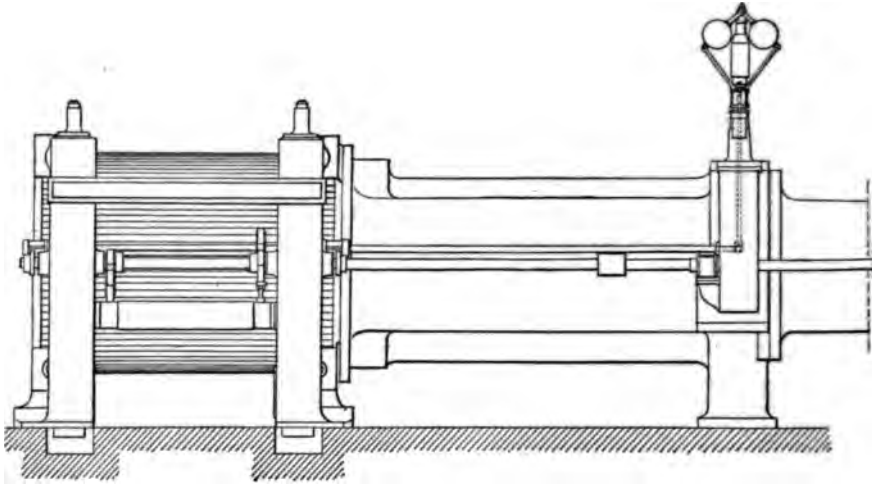
Fig. 622.—Hick: Valve-gear of Eagley Mill Engine. Scale 1/60th.
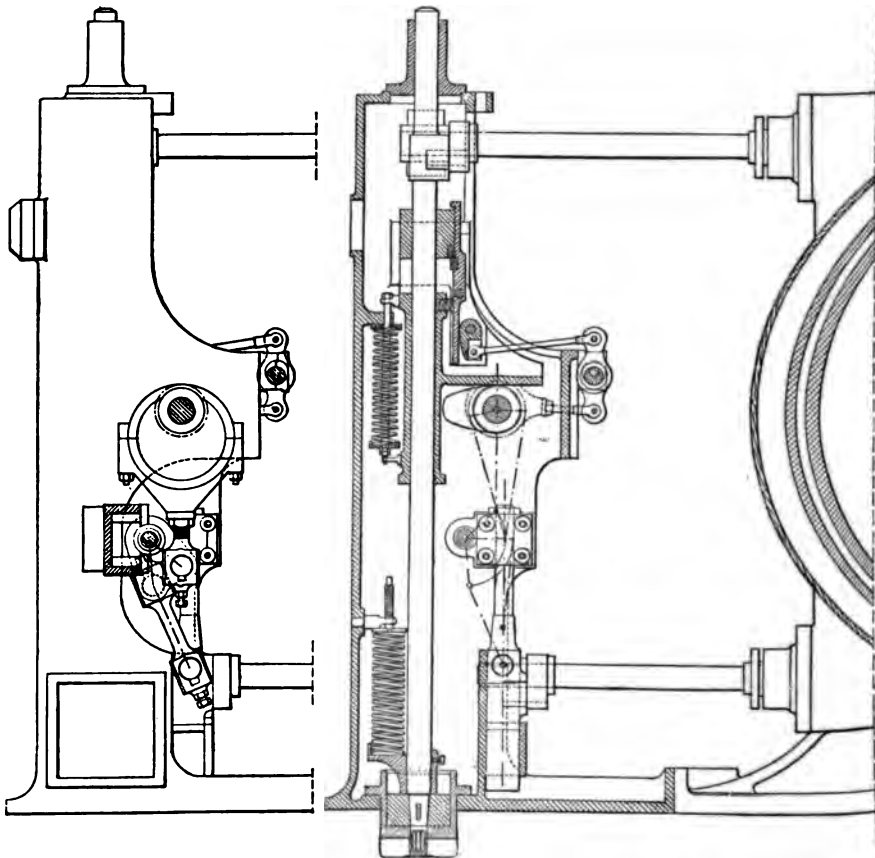
Figs. 623.—Hick: Valve-gear, Eagley Mill. Detail. Scale 1/24th.

piece notched into a block fixed on the upright rod. Thus, as the bracket is lifted, the upright rod also is lifted, and it lifts the end of the steam-valve arm. The valve is rotated on its spindle, and the port opens. In the course of the ascent of the rod the steel pieces are disengaged at the right time by slip-gear; and the rod, thus freed, falls by its own weight and pulls down the valve-arm; and so the valve is closed and the steam is cut off. The sleeve-and-bracket piece is kept always in contact with the cam by means of a helical spring, as shown. The descent of the upright rod is accelerated by a helical spring connected at the lower part, and it is arrested in an 8-inch dashpot at the bottom. A piston is fixed to the lower end of the rod, and an adjustable valve is fitted into the bottom of the cylinder, to regulate the outflow and inflow of air.

The slip-motion is designed to act on the lever piece by means of a trigger, which, pressing on the lower end of the lever, moves the upper arm of it laterally, by which its engaging piece is moved from under that of the upright rod, whereupon the rod drops. The trigger is centred on the sleeve-and-bracket piece, and it is connected with an eccentric on the horizontal shaft, through an intermediate rocking-lever, one arm of which is linked to the eccentric and the other arm to the trigger. The two rocking-levers, one for each steam-valve motion, are made with long centres or sleeves, which reciprocate on a stationary horizontal shaft. By this means each trigger receives a rocking movement, by which it alternately presses the lever out of gear with the upright rod, and leaves it free to engage again with the block on the rod. The lever is caused, when free, to fall into position for engaging with the block, by the pressure of a small spring lodged in the sleeve. The stationary shaft is carried eccentrically in its bearings, and it is adjusted or shifted round automatically by the governor, so that, by advancing or withdrawing the end of the trigger, and so accelerating or retarding its action on the lever piece, the cut-off may take place at an earlier or a later point of the stroke.

The exhaust-valves are worked each by an eccentric on the horizontal shaft, from which, by a bell-crank intermediate lever, a reciprocating movement is imparted to an upright slide-bar, which acts on the arm of the exhaust-valve spindle in the same manner as the upright rods act on the steam-valve arms. The eccentric might be caused to act directly on the slide-bar, but by the intervention of the bell-crank lever, a pause is produced in the movement, when the lower arm of the lever is at and near the dead centre, operating with a minimum extent of movement of the valve.

The Eagley Mill engine was tested by Mr. Osbert Chadwick in May, 1884.[1] The working pressure in the boiler was 43.35 lbs. per square inch, and 798 indicator horse-power were developed. The coal was consumed at the rate of 15¼ cwts. per hour, or 2.14 pounds per horse-power. The feed-water was consumed at the rate of 13,930 pounds, or 223¼ cubic feet per hour; or 17.45 pounds per horse-power per hour; or 8.1 pounds from 52° F.

[1] The summary results of the trial are reported in *The Mechanical World*, September 4, 1885, page 167.
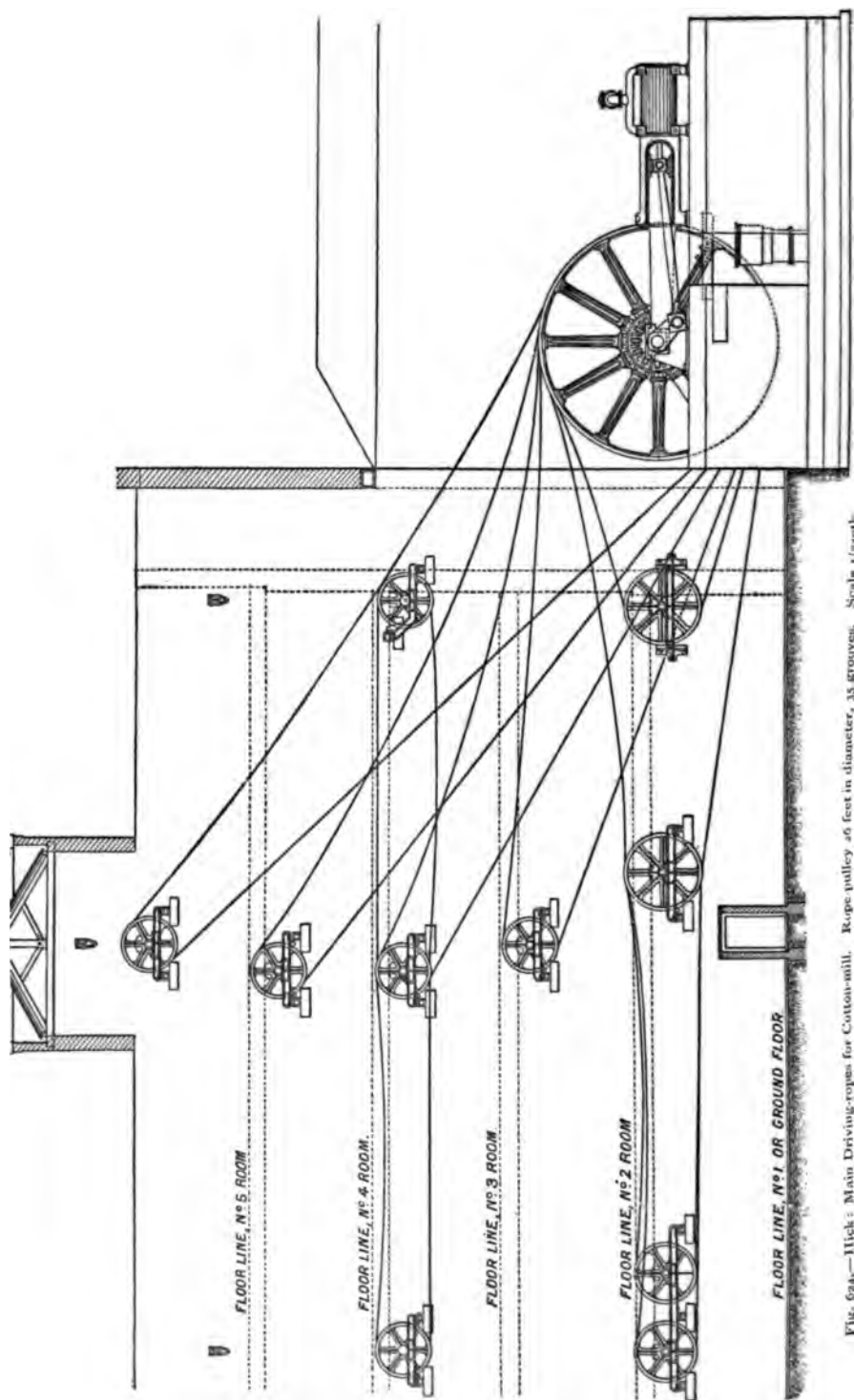
Fig. 624.—Hick: Main Driving-ropes for Cotton-mill. Rope pulley 26 feet in diameter, 38 grooves. Scale 1/192th.

FLOOR LINE, Nº 5 ROOM.

FLOOR LINE, Nº 4 ROOM.

FLOOR LINE, Nº 3 ROOM.

FLOOR LINE, Nº 2 ROOM.

FLOOR LINE, Nº 1 OR GROUND FLOOR.

per pound of coal, or 8.8 pounds from and at 212° F. per pound of coal. The steam-pipe drained off .64 per cent, and the jacket .86 per cent of the total water consumed.

According to sample indicator diagrams from this engine, making 60 turns per minute, with 55 lbs. steam in the boiler, the steam is cut off at about 16 per cent, or about ⅙th of the stroke. It is apparent that the steam is promptly admitted, and assumes its maximum pressure at the commencement of the stroke—a mean pressure of 51 lbs. per square inch above the atmosphere. But there is a wiredrawing before cutting off, to the extent of 5¼ lbs. fall of pressure.

A system of main driving-ropes, arranged by Messrs. Hick, Hargreaves, & Co., for distributing the power to the different floors of a cotton-mill, is illustrated by fig. 624, showing an elevation in section of the rope-chamber and the engine-house. There are in all five floors to be served, the levels of which are indicated in the figure, by cotton ropes proceeding from the rim of the fly-wheel. The engine is a horizontal Corliss engine, having a stroke of 6 feet, of 1100 indicator horse-power. The rope-wheel is 26 feet in diameter, and it makes 55 revolutions per minute, equivalent to a speed of piston of 660 feet per minute, or to a circumferential speed, or rope speed, of 4490 feet per minute. It is grooved for 35 ropes. The power is distributed by six groups of ropes to six rope-pulleys and shafts, from two of which power is transmitted by additional ropes and pulleys to four other shafts, making a total of ten shafts driven directly or intermediately from the rope chamber. The distribution is shown in the following tablet:—

Distribution of 1100 Indicator Horse-power from a Rope Fly-wheel in a Cotton-mill.

FLOOR.	No. of Pulley.	Diameter of Pulley.		Revolutions per Minute.	Number of Ropes.
	No.	feet.	ins.	turns.	ropes.
Ground floor, No. 1 Room...	1	8	3	173.3	4
Do. do. ...	2	8	3	173.3	5[1]
No. 2 Room.....................	3	5	8¾	250	5
No. 3 Room.....................	4	5	8¾	250	7[2]
No. 4 Room.....................	5	5	8¾	250	7
No. 5 Room.....................	6	5	8¾	250	7
Total number of ropes from fly-wheel.................. 35					

[1] From a pulley of 4 grooves on the same shaft, 8 feet 3 inches in diameter, power is transmitted to two pulleys, 6 feet 4 inches in diameter, by two ropes for each, making 225.7 turns per minute.

[2] Two pulleys, 5 feet 8¾ inches in diameter, are driven by two ropes to each from No. 4 pulley.

From the given data, the power distributed for each rope is $1100 \div 35 = 31.4$ indicator horse-power; and, for a rope speed of 4490 feet per minute, it appears that the tensional force given off to the ropes—no allowance being made for the internal resistance of the engine—is $\dfrac{1100 \times 33,000}{4490} = 8084$ pounds, or

3.61 tons, which is at the rate of $(8084 \div 35 =)$ 231 pounds of tension on each rope. Allowing that 10 per cent of the indicator power is neutralized by engine resistance, the effective or net stress on the ropes would be at the rate of 208 pounds per rope. The ropes are 5 inches in circumference, or nearly $1\frac{5}{8}$ inches in diameter, or 2 square inches in sectional area; and the net stress is at the rate of $(208 \div 2 =)$ 104 pounds per square inch of section.

AUTOMATIC BARRING ENGINE.

This is a contrivance for starting a steam engine of large size, in cases where the crank is so near to either end of the stroke that the leverage on the main shaft is insufficient to enable the engine to start when steam is turned on. It is useful also for barring or slowly turning round the engine for purposes of repair, or for mounting or dismounting driving-bands. A form of barring engine employed by Messrs. Hick, Hargreaves, & Co. is shown in figs. 625. A worm is fixed on the end of the main shaft of the
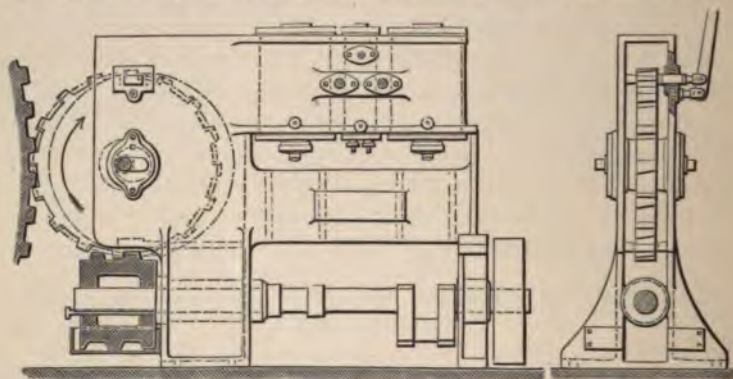
Figs. 625.—Hick: Automatic Barring Engine. Scale 1/24th.

barring engine, which is double-cranked, and lies low, and is driven by two 9-inch vertical steam cylinders of $7\frac{1}{2}$-inch stroke. A toothed wheel is turned by the worm, and it also gears with the rack on the circumference of the fly-wheel, a part of which is shown. When the fly-wheel is turned round by the action of the barring engine sufficiently to enable the main engine to move itself, it overtakes the worm-wheel, and pushes it out of gear, freeing itself to move clear of the barring engine. For the sliding horizontal movement of the axle of the worm-wheel, the axle runs in horizontal oblong bearings. The worm-wheel, in being pushed off horizontally, acts as a bell-crank lever, having its fulcrum at the worm, and the power being applied by the rack. When it is, on the contrary, to be pushed into gear with the fly-wheel, it is temporarily fixed at the top by the pressure of a stud forced against it laterally through a hand-lever, and an inverted bell-crank action takes place, when steam is turned on the barring engine—the fulcrum being at the top of the wheel, and the power being applied by the worm. Thus, the machine falls into gear and out of gear automatically. When it is applied to internal racks, the cylinders are placed below and the shaft above.

CHAPTER XXV.—PAIR OF HORIZONTAL TANDEM COMPOUND STEAM ENGINES.

CONSTRUCTED BY MESSRS. JOHN MUSGRAVE & SONS, BOLTON.

PLATE VII.

(Cylinders 24 inches and 46 inches diameter, 6 feet stroke.)

The tandem engines constructed for the Whitelands Twist Company, Ashton-under-Lyne, erected in 1883, are illustrated by Plate VII., in general arrangement, with the distribution of the power. The bed or bed-frame is a massive hollow casting, or number of castings bolted together, lying continuously on the foundation, upon which the cylinders and the crank-shaft are supported—the second cylinder behind the first. The condenser and
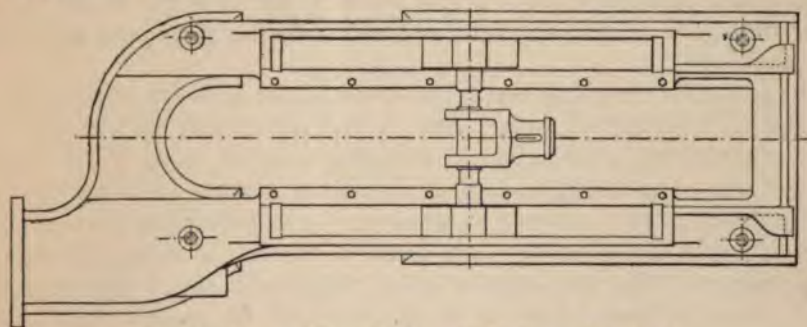
Fig. 626.—Musgrave & Sons: Bed-frame, Middle Piece. Scale 1/48th.

air-pump are placed vertically under the middle of the engine, and are worked off the crosshead. The engine is fitted with Corliss valves and

At 2d Cylinder.   At 1st Cylinder.   At Slides.
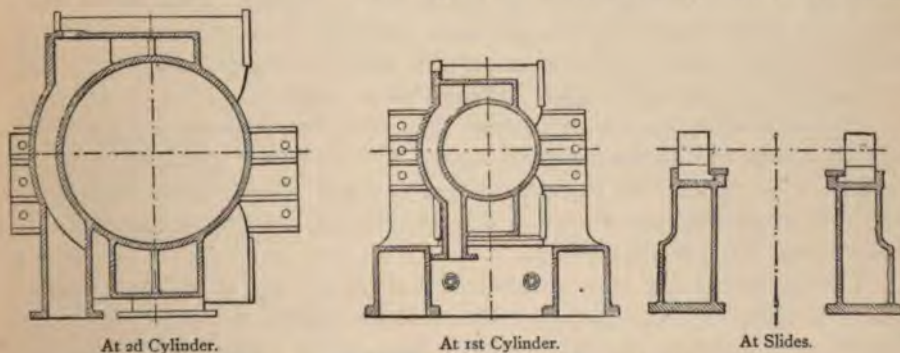
Figs. 627.—Musgrave & Sons: Transverse Sections. Scale 1/48th.

Musgrave's slip-motion. The power is given off direct from the rim of the fly-wheel or drum by means of ropes.

The bed-frame is in three pieces, and it consists of two parallel box-girders, 3 feet 9 inches apart between centres, which support the cylinders and the guides, merging in a box-girder supporting the main pedestal.

The parallel girders are in two pieces, parted transversely, of which one piece is underneath the first cylinder, and the other piece forms the slides. They are joined under the front end of the first cylinder with two 2-inch bolts and nuts, through the transverse ribs forming the ends of the pieces, and two dowels and four cotters at the sides. The limbs of the piece under the first cylinder are united by a cross girder under the back end of the cylinder, besides the transverse rib already mentioned; and the piece extends to the front end of the second cylinder, and is formed with strong bracketed flanges, $2\frac{1}{4}$ inches thick, for connection to this cylinder with six 2-inch turned bolts and nuts. This cylinder is cast with a foot on the back end, which is bedded on to a surface-plate recessed into the stone-work of the foundation level with the top, and fastened with two 2-inch holding-down bolts going to the bottom of the foundation. The first cylinder is similarly fastened. It is bolted down at the back end to the bed-frame with two $1\frac{3}{4}$-inch bolts and nuts; and it is also bolted at the front end to the parallel girder slide-piece with bracketed flanges, $2\frac{1}{4}$ inches thick, and six 2-inch bolts and nuts.

The section of the girder under the first cylinder is shown in figs. 627. It is 18 inches high and 14 inches wide, of $1\frac{1}{4}$-inch metal; open at the base, where it is widened to 19 inches, by flanges $2\frac{1}{2}$ inches thick. At the guide-bars the frame is a complete box, or four-sided casting, so formed to span the gap in which the condenser is situated. It is 2 feet 9 inches high, with 1-inch metal in the sides, $1\frac{3}{4}$-inch metal in the top or slide, and $2\frac{1}{2}$-inch in the bottom. The single-girder piece, with which the main pedestal is cast in one, is 20 inches wide at its junction with the middle piece, joined with eight $2\frac{1}{4}$-inch bolts and nuts. It is widened to $24\frac{1}{2}$ inches to form the pedestal with 2-inch metal sides. The bed-frame is planed on the upper side to receive the cylinder foot-flanges. It is also planed on the lower surfaces. It is about $39\frac{1}{2}$ feet in length, and is fastened with twelve holding-down bolts—four $2\frac{1}{2}$-inch for each pedestal piece, four 2-inch for the middle or slide piece, and four 2-inch for the cylinder or end piece. The two engines are $18\frac{1}{2}$ feet apart between their centre-lines.

The cylinders, shown in section, figs. 627, are respectively 24 inches and 46 inches in diameter, with a stroke of 6 feet; the areas being in the ratio of 1 to 3.68. The engines, at their normal speed, make 50 turns, or 600 feet of piston, per minute. The maximum working pressure in the boilers is 90 lbs. per square inch.

The cylinders are not steam-jacketed; they are felted and lagged. The first cylinder is of $1\frac{1}{4}$-inch metal, and the second is of $1\frac{1}{2}$-inch metal. Steam is brought to the first cylinder from below, and is conducted by a passage cast on one side, to the steam valves at the top of the cylinder. The steam is exhausted by the exhaust-valves at the bottom, and is conducted to the second cylinder by a pipe and a passage on one side of the second cylinder to the steam-valves at the top, as in the first cylinder. This passage is provided with a safety-valve, to prevent steam getting into the second cylinder at so high a pressure as would risk the breaking of it, when

Diameter of 1st Cylinders, 24 in.
    ,,   2nd   ,,   46 in.
Stroke of Pistons, 6 ft.
Speed, 50 Revolutions per minute.
Indicator Horse-power, 1120 H.P.
Air-pump, 33 in. in diameter; stroke 2 ft. 4 in.
Main Shaft, 17½ in. in diameter; hollow.
Rope Pulley Fly Drum, 30 ft. in diameter,
    grooved for 35 ropes, 60 tons.
Total Weight for pair of Engines, 198 tons.

BARRING ENGINE.   MA

SCALE 1–96TH, OR ⅛ INCH = 1 FOOT.

PLATE VII.
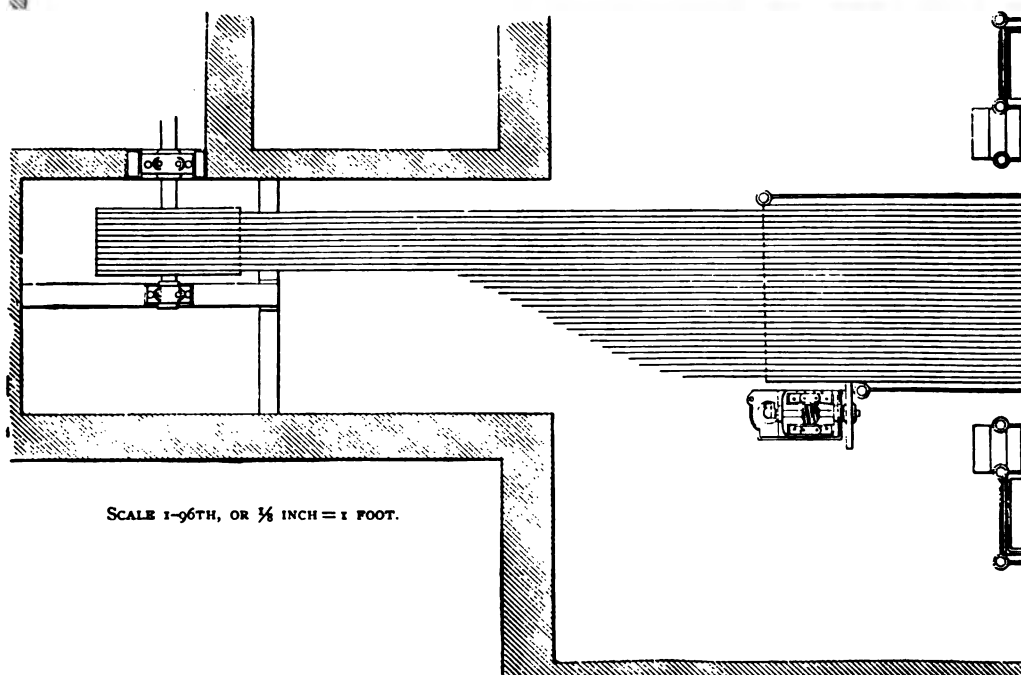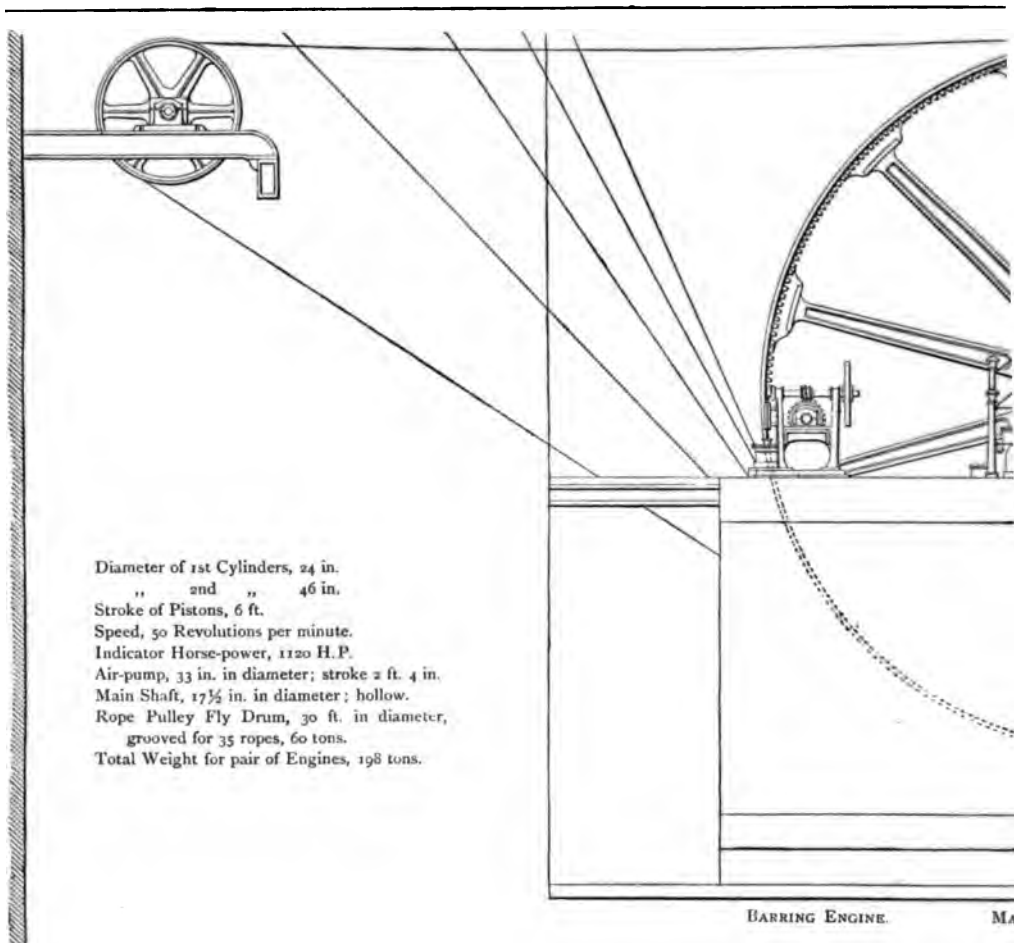
PAIR OF HORIZONTAL TANDEM COMPOUND
STEAM ENGINES,

CONSTRUCTED BY MESSRS. JOHN MUSGRAVE AND SONS, BOLTON.

FIG 1.—LONGITUDINAL ELEVATION.

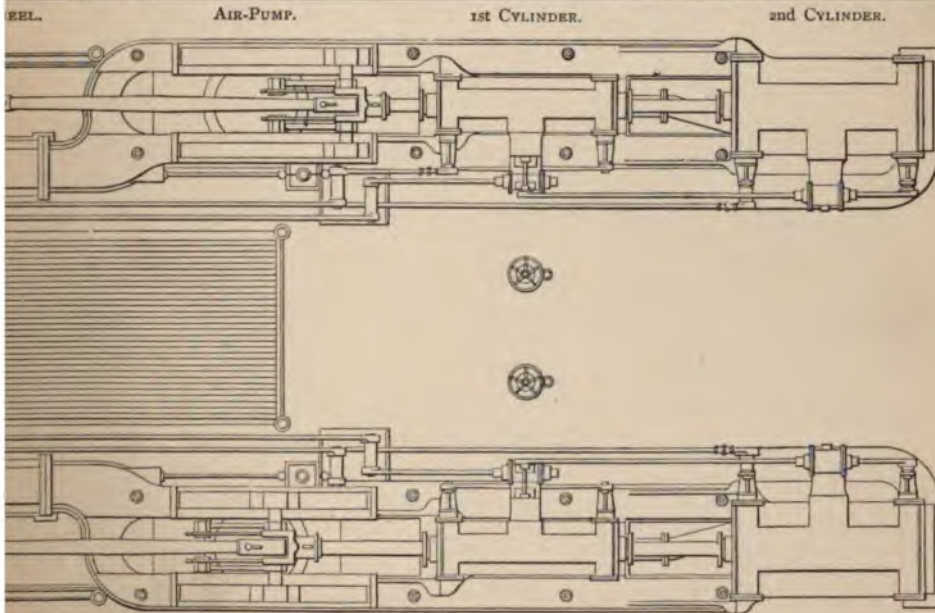EEL.   AIR-PUMP.   1st CYLINDER.   2nd CYLINDER.
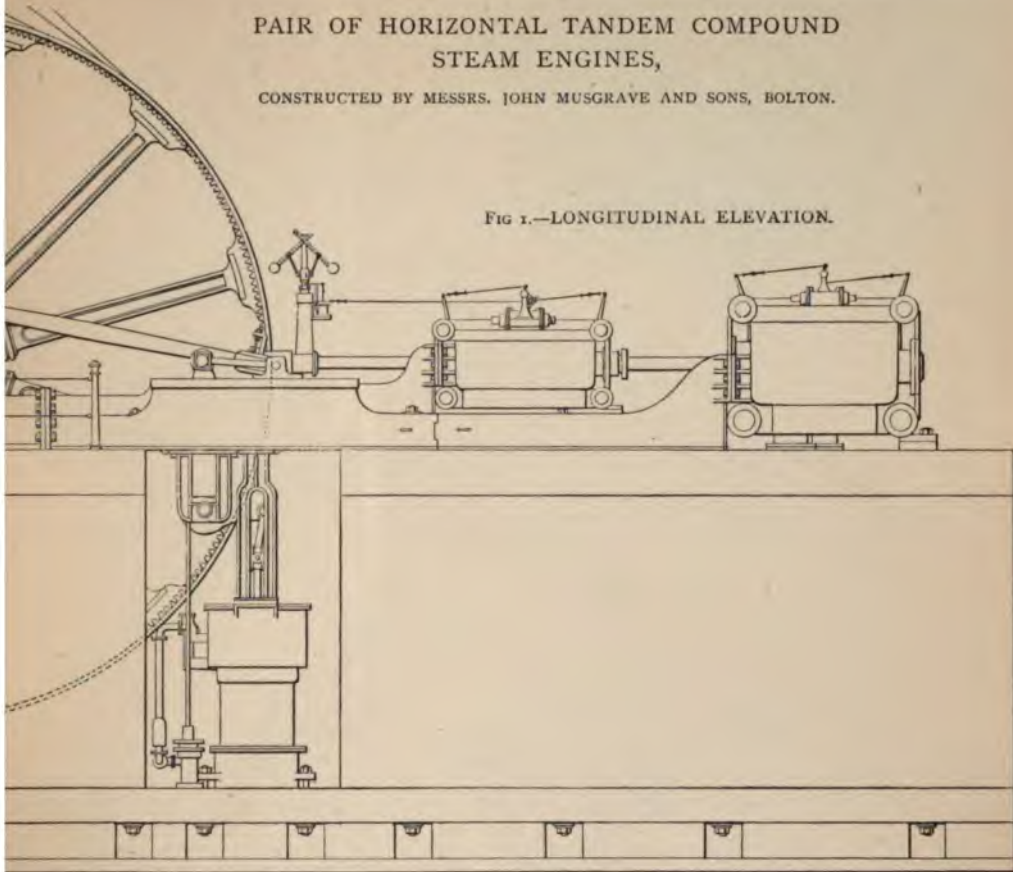
IG. 2.—PLAN.

blowing through.   Thence the steam is exhausted below, to the condenser. The steam-pipe and stop-valve for each engine are 8 inches in diameter.

The system of valves and valve-gear has already been described and illustrated, pages 49 and 50.   The motion is derived from two eccentrics on the main shaft, one for the steam-valves and one for the exhaust-valves. The eccentric-rods are not in line with the rods which are connected to the valve-levers; and to transfer the motion laterally, the ends of the eccentric-rods are pinned to rocking carriers, which are hinged to the floor, through which the motion is transferred laterally to the rods pinned to the valve-levers. The slip-gear of the first cylinder is controlled by the governor. The range of cut-off in the first cylinder extends from 0 to 60 per cent of the stroke; that of the second cylinder is regulated by hand.   The governor is cross-armed.

The pistons are packed with Mather & Platt's rings.   The piston-rods are of steel, $5\frac{1}{4}$ inches in diameter at the front, and $4\frac{3}{4}$ inches at the back. Their total length is 23 feet 1 inch.   The front piston-rod is fastened by a steel cotter into a wrought-iron crosshead, carrying cast-iron slide-blocks, which slide on the tops of the girder frame, as before noticed.   The crosshead is forked; the pin is 6 inches in diameter, and $8\frac{1}{2}$ inches long between the forks.   The forks are 3 inches wide, and are 3 inches thick round the pin.   The socket for the piston-rod is $8\frac{1}{2}$ inches in diameter and $14\frac{1}{2}$ inches long, with a cotter $1\frac{1}{4}$ inches by $5\frac{1}{2}$ inches.   The slide-blocks are 24 inches long by 9 inches wide, and they are held down by keeps, which overlap them by 1 inch.   They are each formed with an eye $7\frac{1}{2}$ inches wide, to take the ends of the crosshead-pin.   The slide-surfaces on the frame are 3 feet $4\frac{1}{2}$ inches apart between centre-lines.   The pin is formed with a $4\frac{1}{2}$-inch journal at each side of the crosshead to work the air-pump, by a bell-crank movement.   The slides are self-lubricating.

The connecting-rod is of wrought iron.   It is 15 feet long, or five times the length of the crank.   It is 6 inches in diameter at each end, and swelled to 8 inches at the middle.   The bearings are, for the cross-head end, 6 inches in diameter, $8\frac{1}{2}$ inches long; and for the crank end 8 inches in diameter, 10 inches long.   The crosshead end is made with a strap and gib and cotter; and in addition, a bolt and nut to prevent the strap from springing open.   The cotter is secured by a screw through an eye on its upper end, with a pair of nuts.   The screw is not forged solid with the gib, but is separate, and pinned to it.   The crank end is forged solid, and is fitted with a cotter and a safety-screw pinned to the end, with nuts to secure the cotter.   The steps are of phosphor-bronze.   The

Fig. 628.—Musgrave & Sons: Section of Pedestal. Scale 1/48th.

main shaft is of Whitworth's fluid-compressed steel, $17\frac{1}{2}$ inches in diameter, hollow.   The journals are 16 inches in diameter and 28 inches long.   The boss for the drum is $19\frac{1}{2}$ inches in diameter.   The crank is of wrought iron and the pin is of steel, 8 inches in diameter and 10 inches long for the journal.   The pedestal, fig. 628, is formed with a groove or small trough at

each side, for catching the oil which leaves the journal, and delivering it into an oil-well, from which it is returned by a small pump into the oil-box. Continuous lubrication is thus effected. The step is of phosphor-bronze, in four parts, with adjustable screws and cotters.

The fly-wheel or drum is 30 feet in diameter and 7½ feet wide, con-
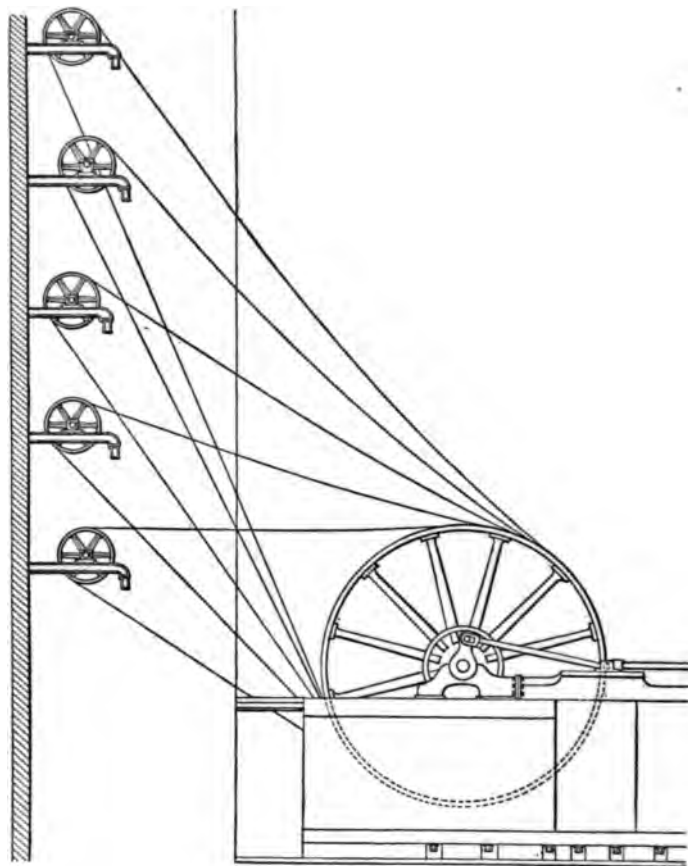
Fig. 629.—Musgrave & Sons: Main Driving Ropes for a Cotton-mill. Scale 1/240th.

structed with two sets of arms, and grooved for 35 ropes 1¾ inches in diameter.

The condenser and air-pump are placed vertically, side by side, below the frame-bed. The condenser is 44 inches in diameter, 4 feet 2 inches high. At the bottom it is bottle-neck shaped, 28 inches in diameter, 6½ inches high; making the total height 4 feet 8½ inches. The exhaust branch is fixed to the top of the condenser, and a 6-inch injection branch is fixed to the side, near the top, so that the water flows on to a perforated plate suspended directly under the exhaust-pipe.

The air-pump is 33 inches in diameter, worked by a bell-crank lever from the crosshead, with a stroke of 2 feet 4 inches. The valves are fitted

with india-rubber lids. The valve in the air-pump bucket is placed near the bottom of the bucket, so that it works very low down in the foot-box: thus reducing the space between the bucket and foot-valve, and clearing out the air.

A relief-valve is placed in the injection-pipe near the condenser, in order that, if the injection-valve be suddenly closed, the concussion of the water suddenly arrested may not break the pipe or pipe-joints. The relief-valve is specially necessary when the water travels a long distance.

The feed-pump for the boilers is fixed beside the air-pump, and is worked off the back of the bell-crank. It is single-acting, with a 5-inch ram.

The manner of the distribution of the power of the engine through driving ropes, to the floors of a cotton-mill, is shown in fig. 629.

A barring engine, figs. 630, is supplied to turn the rope-drum at starting, or on other occasions when it is required to turn the engine. It is worked by a small vertical steam engine at one end, by which a horizontal worm-shaft is turned. The worm

Figs. 630.—Musgrave & Sons: Barring Engine.

gears with and turns a wheel, on the axle of which a small spur-wheel is fixed.

A frame is slung on the same shaft, carrying another small spur-wheel which gears with the first wheel, and can be placed in gear also with the rack, which is fixed inside the rim of the rope-drum by swinging the frame.

The wheel may be thus placed in gear by hand, and then the steam can be turned on. When the drum has got into motion, the gear can be easily disengaged by a reverse swing of the frame.

The total weight of the pair of engines, with the fly-drum, is 198 tons. The weights of separate parts are as follows:—

	Tons.	Cwts.
1 46-inch low-pressure cylinder and covers..........................	8	5
1 24-inch high-pressure cylinder and covers........................	3	3
1 46-inch piston..	1	6
1 24-inch piston...	0	7¼
1 piston-rod for both cylinders.......................................	0	18¼
1 connecting-rod, complete..	1	4½
1 crank	1	4¼
1 crank-pin...	0	3

	Tons.	Cwts.		
2 parts of bed-frame, under guide-bars and high-pressure cylinder..	12	9		
1 pedestal part of bed-frame, with steps, cap-bolts, &c.	4	16		
			17	5
1 air-pump and condenser with foot-box			5	15
1 air-pump lever			1	0½
1 air-pump bucket and rod			0	14¾
Hanger fixings, slides, blocks, crosshead side links, and top links			1	18
Sundry parts:—Steam-pipes and other pipes, valves, governor, &c., not included in the separate weights above given; holding-down bolts, washers, and plates, &c.			22	16¾
Total for one engine, exclusive of parts common to both engines...............................			66	1¼
For two engines..			132	2½
Main shaft..			5	17½
Fly-drum			60	0
Total weight of both engines..........................			198	0
Total weight per engine..............................			99	0

The foundations are of brick, except a course of stone at the top, 2 feet thick, on which the frame is bedded, and a 6-inch course of flag-stones at the bottom. They are each 57 feet long, 10¼ feet wide, 15½ feet deep from floor-line to the top of the hand-holes. These are 18 inches deep over the bottom course of brick; and the total depth of the foundation is about 17½ feet. The drum-race is 8 feet wide.

The engines have been tested for consumption and performance. The coal—engine slack—consumed per week, making 56½ hours of working time, for all purposes, including the steaming of the mill, keeping up steam during meal times and week ends, was 70 tons 2¼ cwts., or 24.82 cwts. per working hour, or 2.48 pounds per indicator horse-power per hour. The feed-water was consumed at the rate of 17 pounds per horse-power per hour,

according to which 6.85 pounds of water was evaporated per pound of coal. Sample average indicator diagrams are given in figs. 631, from which it appears that the initial pressure in the first cylinder was, say, 79 lbs. per square inch above atmospheric pressure; that the steam was cut off at about one-fourth of the stroke, and was expanded nominally $(4 \times 3.68$ (ratio of cylinders) $=)$ 14.72 times. The indicator power was collected thus:—

	No. 1 Engine.	No. 2 Engine.
1st cyl.,	311.53 H.P.	309.07 H.P.
2d ,,	249.83 ,,	249.83 ,,
	561.36 ,,	558.90 ,,

Making together 1120.27 indicator horse-power.

According to the stated results of trials of other engines of the same type, manufactured by Messrs.

Figs. 631.—Indicator Diagrams from Musgrave's Tandem Compound Steam Engine, Whitelands Mill.

Musgrave, the rates of consumption of fuel per hour per indicator horse-power are as follows. The fuel includes that which was consumed for steaming the mill and all other purposes:—

Lee Spinning Company, Atherton, Bolton,............................... 2¼ lbs.
Shawcross, of Rochdale, 350 I.H.P., 29 tons 9 cwts. for 58 hours,...... 3¼ ,,
Marshfold Mill, Bolton, 590 I.H.P., ... 2.33 ,,
Atherton Spinning Company, Bolton, 740 I.H.P., 47 tons per week,... 2.45 ,,

CHAPTER XXVI.

HORIZONTAL COMPOUND CORLISS RECEIVER CONDENSING STEAM ENGINE, ASTLEY MILL COMPANY, DUKINFIELD.

CONSTRUCTED BY MESSRS. GOODFELLOW & MATTHEWS, HYDE, NEAR MANCHESTER.

PLATE VIII.

(Cylinders 32 inches and 60 inches in diameter, stroke 7 feet.)

In this compound steam engine the first and second cylinders are placed parallel to each other. They are tied each by a back or bayonet frame directly to the main bearings; and the cylinders, frames, and main bearings are supported directly on the foundation. The cylinders work to one main shaft, which carries a rope driving-wheel or pulley. They are fitted with Corliss valves, worked by Goodfellow & Matthews' improved Ramsbottom's trip-gear. See Plate VIII. and fig. 632.

The first and second cylinders are respectively 32 inches and 60 inches
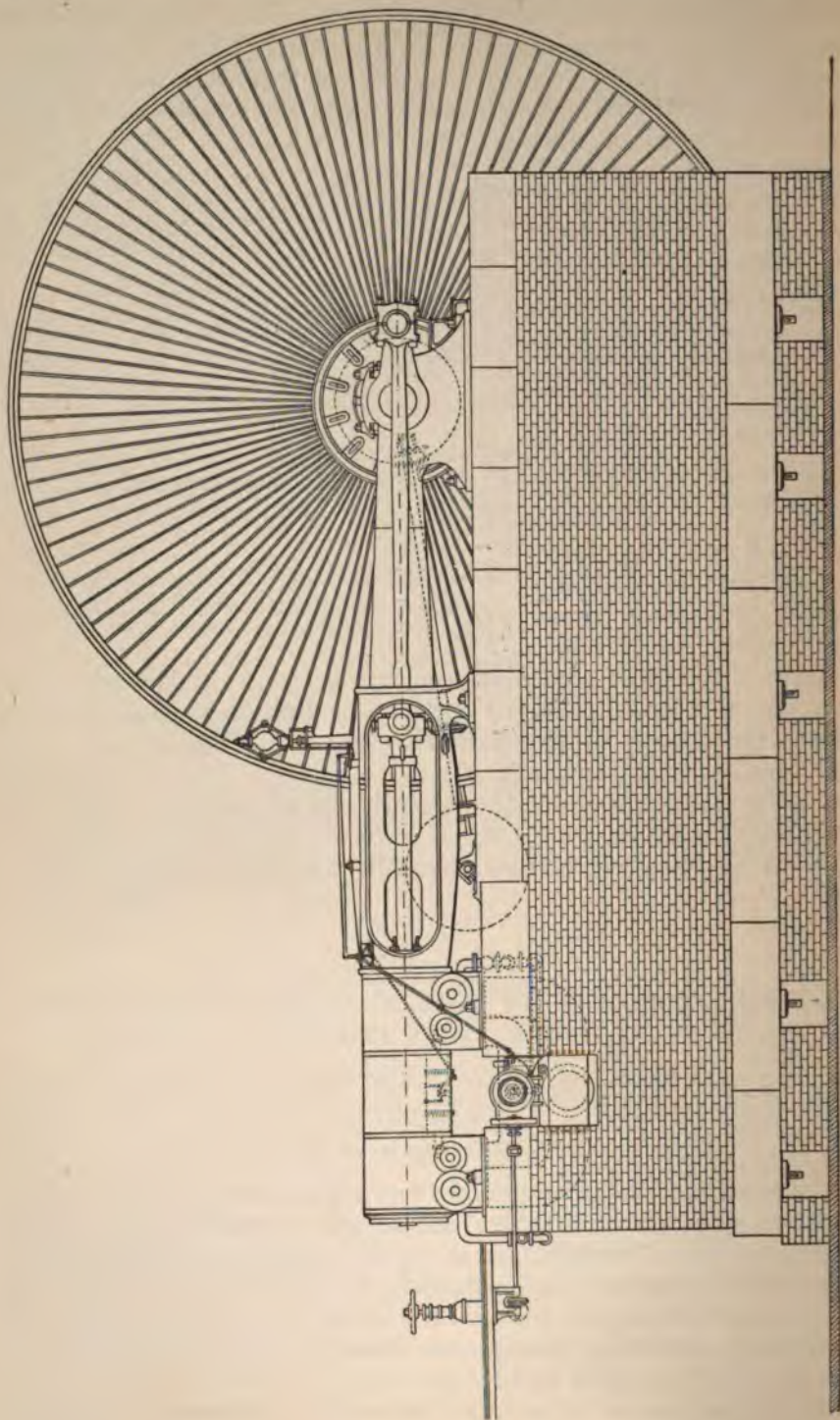
Fig. 632.—Goodfellow's Compound Receiver Steam Engine, Astley Mill, Dukinfield : Elevation of First Cylinder and Connections.   Scale 1/96th.

HORIZONTAL COMPOUND CORLISS RECEIVER STEAM ENGINES,

CONSTRUCTED BY MESSRS. GOODFELLOW AND MATTHEWS, HYDE,

FOR THE ASTLEY MILL COMPANY, DUKINFIELD.

SCALE, 1-96TH, OR ⅛ INCH = 1 FOOT.
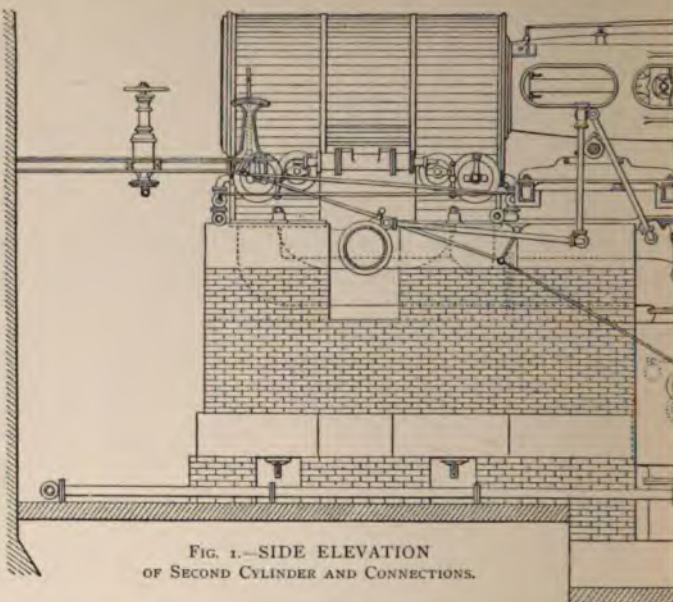
FIG. 1.—SIDE ELEVATION
OF SECOND CYLINDER AND CONNECTIONS.

PLATE VIII.
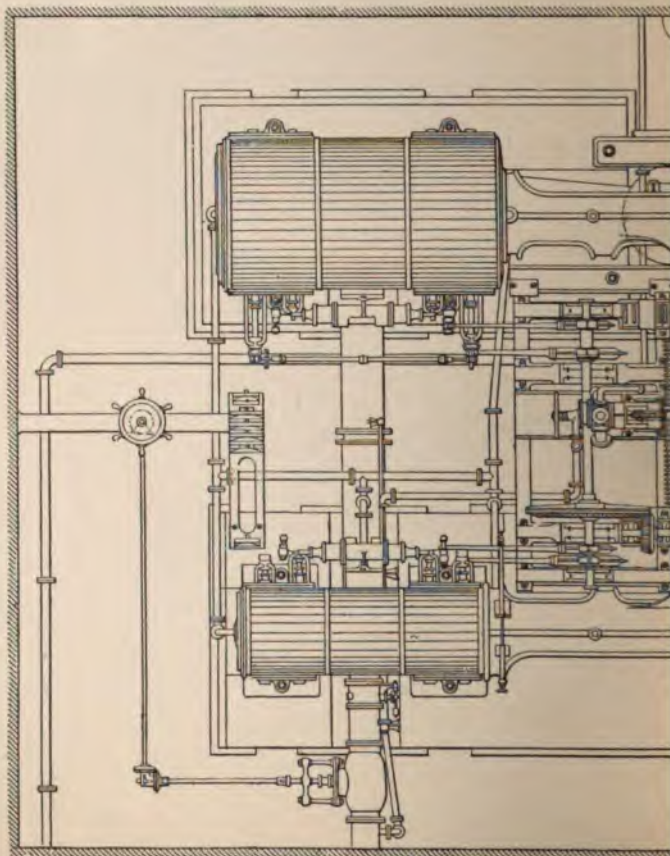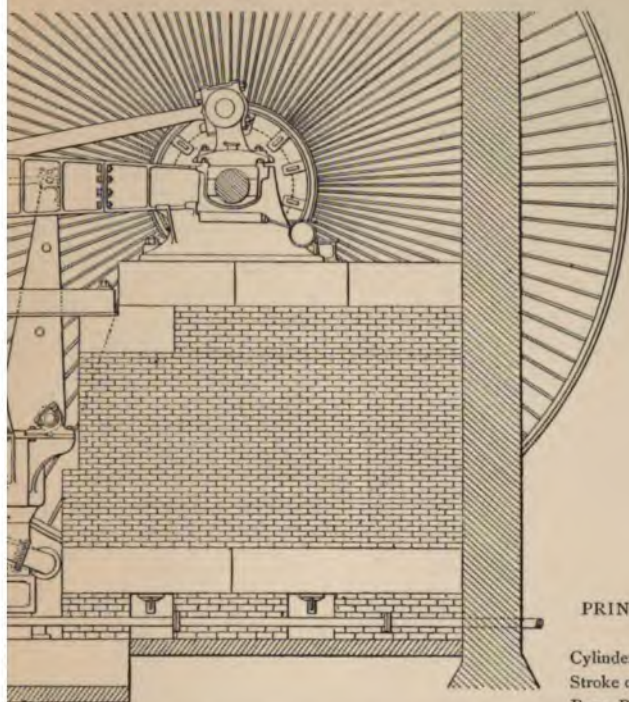
PRINCIPAL DIMENSIONS.

Cylinders, 32 in. and 60 in. in diam.
Stroke of Pistons, 7 ft.
Rope Pulley for 32 Ropes, 34 ft. in
    diameter, 78 tons weight.
Main Shaft, 19 in. in diameter.
Total Weight, 215 tons.
Speed, 50 Revolutions per minute.
Indicator Horse-power, 1300 I.H.P.
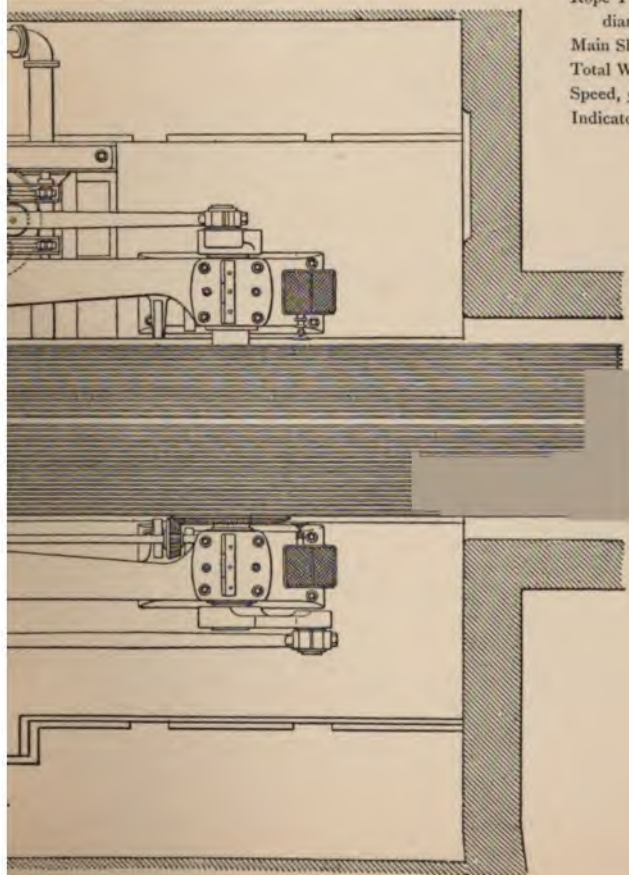
in diameter, with a stroke of 7 feet.   Their capacities are as 1 to 3.52. They are not steam-jacketed.   The normal speed is at the rate of 50 turns, or 700 feet of piston, per minute.   The engine is designed to indicate 1300
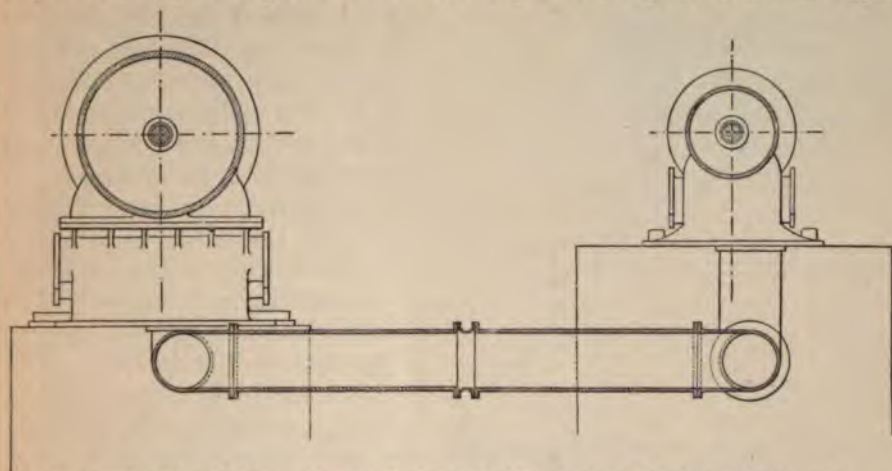
Fig. 633.—Goodfellow & Matthews' Receiver Engine, Astley Mill: Section of Cylinders and Receiver-pipe.
Scale 1/72d.

horse-power, with an effective pressure of 100 lbs. per square inch in the boiler, the steam being cut off at one-fourth of the stroke in each cylinder, making a nominal expansion-ratio of 16.   But the normal working pressure in the boiler is 90 lbs. per square inch.   The rope-pulley is 34 feet in diameter, having grooves for 32 ropes 1¾ inches thick.   At the normal speed the circumferential velocity of the pulley is 5340 feet per minute; and in transmitting 1300 indicator horse-power, taking the proportion of 90 per cent transmitted, the circumferential stress on   the   ropes   is $1300 \times \dfrac{90}{100}$

$\times 33,000 \div 5340 = 7229$ pounds, or 3.23 tons; or 213 pounds per rope.

The cylinders, shown separately in figs. 633 and 634, are respectively 1¾ inches and 1⅞ inches in thickness.   The cylin-

Fig. 634.—Goodfellow's Engine: First Cylinder and Valve-chests. Scale 1/20th.

der covers, fig. 634, are of box section, well ribbed, of 1¼-inch metal, with flanges 2 inches thick.   They are connected transversely by a compact receiver in the form of a straight pipe, into which the steam is exhausted

from the first cylinder, and from which the second cylinder is supplied. This pipe is of cast iron, 20 inches in diameter, and 1 inch thick. It is about 18 feet in length, and the total receiver capacity amounts to about 112 cubic feet, which is nearly three times the capacity of the first cylinder. It is parted at the middle, and made up with an expansion-joint of copper.

Fig. 635.—Goodfellow & Matthews' Engine, Astley Mill: Section of Bed-frame. Scale 1/48th.

The frame is cast in one piece, of 1⅜-inch metal, reaching from the cylinder up to the junction with the pedestal end. The frame follows a cylindrical form, 3¼ feet in diameter internally, as shown in the cross section, fig. 635, with free openings at the sides. The pedestal end, figs. 636, is a hollow casting, of 1¾-inch metal, except the seat for the brasses, which is 3 inches thick, and the sole or base, which is of 2¼-inch metal. The sole is 7 feet 11 inches long, 3½ feet wide. The bearing is constructed for a journal, 17 inches in diameter, 40 inches long, and it stands 3¼ feet high to the axis. The brasses are in four pieces—top, bottom, and two sides, of which the sides, forward and backward, are adjustable horizontally, by means of a wedge at each side, movable vertically by means of a 2-inch screw which engages a. nut lodged in the wedge. The upper end of each screw takes its bearing with a collar on the cap of the pedestal, and is formed square to take the screw-key. The cap is of cast iron, formed at the sides to clip the pedestal, and held down by means of two pairs of 2½-inch bolts and nuts. The under face of the cap is formed with ribs or flanges, which bear upon corresponding flanges cast on the upper section of the bearing. The pedestal is held down with four 2¾-inch bolts and nuts through its base. Oil for lubrication is supplied to the bearing by means of two small pumps; and
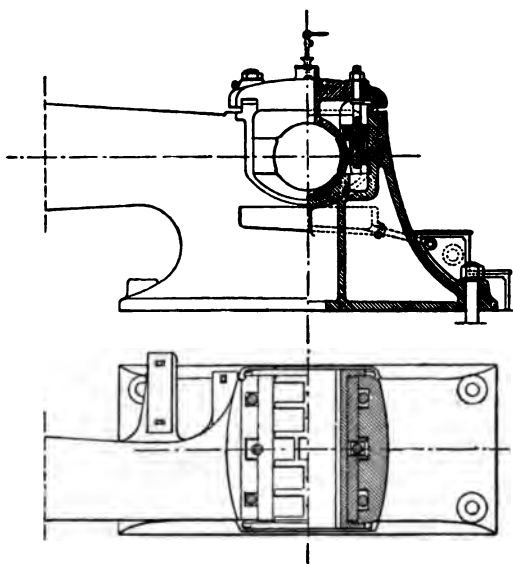
Figs. 636.—Goodfellow's Receiver Engine: Pedestal. Scale 1/48th.

after being used it is sieved and then received into a trough on each side of the pedestal, whence it is passed through gauze filters and returned to the reservoir formed by the steps at the outer side of each pedestal. The steps, shown in shade on the plan, figs. 636, are chequered to afford a good foothold for access to the pedestal caps.

The pistons, figs. 637, are of cast iron, in two pieces,—the body and the junk-ring,—united by screw-bolts. The body and the ring are formed with flanges at the lower semi-circumference, by which the bearing surface of the piston is augmented. The packing is on Mather & Platt's system,—a pair of hard cast-iron rings, of channel section, and a steel coil inside the rings. The piston-rods are of Siemens-Martin steel. They are 7 inches in
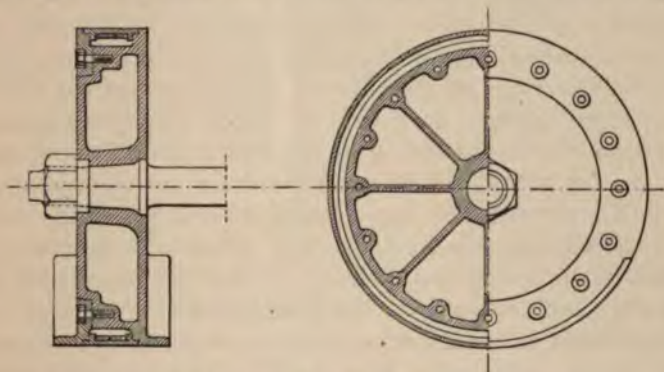
Figs. 637.—Goodfellow's Engine: First Piston. Scale 1/20th.

diameter, and are formed conically to fit into and through the pistons, into which they are fixed by a deep wrought-iron nut, secured by a pin through the end of the rod. The screw and nut are chased with a "buttress" thread. The crossheads are vertical, carrying slides above and below, adjustable by screws and nuts. The slides are circled in cross section to fit the guides in the frame, which are bored out. The gudgeon of each crosshead is of steel, $7\frac{1}{2}$ inches in diameter, 12 inches long. The brasses are in halves lodged in a recess cut horizontally out of the head of the piston-rod, keyed on the rod; and fixed with a cap and two $4\frac{1}{2}$-inch steel bolts and nuts.

The connecting-rods are of wrought iron, with cap-and-bolt ends, $17\frac{1}{2}$ feet long, or five times the length of the cranks; 7 inches in diameter at the crosshead end, $7\frac{1}{2}$ inches at the crank end, $9\frac{1}{2}$ inches at the middle.

The main shaft is of Whitworth compressed steel, 19 inches in diameter in the body, increased to 24 inches in the fly-pulley boss. The journals, two in number, are 17 inches in diameter, 40 inches in length, and are 11 feet $6\frac{1}{2}$ inches apart between centres. The cranks are finished to a radial length of $3\frac{1}{2}$ feet. The crank-pins are of Whitworth compressed steel, having journals 10 inches in diameter, 10 inches long. The rope-pulley is, as before stated, 34 feet in diameter. It is in two half-widths

parted by the barring rack. It is fixed on the main shaft by eight steel staking keys 7 inches wide, four to each half-width.

The valves are Corliss valves, worked by the improved Ramsbottom's trip-gear, figs. 638. The steam-valves are $8\frac{3}{4}$ inches in diameter for the first cylinder, and 13 inches for the second cylinder; the exhaust-valves are $13\frac{1}{2}$ inches and 19 inches respectively. The eccentrics for working the steam-valves have $7\frac{1}{2}$ inches of throw; and those for the exhaust-valves have respectively $12\frac{5}{8}$ inches and $13\frac{5}{8}$ inches of throw. The chief peculiarity of this system of trip-gear consists in tripping by means of knuckling links instead of by catches, as, in various forms, is common to other systems. The "carrier-rail" through which the tripping movements are effected, is suspended horizontally by two vibrating links, and is coupled at one end to the eccentric-rod. Driven directly by the eccentric, it receives a constant reciprocating longitudinal movement, $7\frac{1}{2}$ inches in extent. Two levers have their bearings on the carrier-rail, and are carried with it. One arm of each lever, or finger as it may be called, comes into contact with a stationary trigger suspended above the rail, and is thrown out of the vertical position; the other arm of the lever consequently unsettles a knuckle-joint, through which, when set, the steam-valve is opened. The unsettling or doubling of the knuckle sets free the valve, which is simultaneously closed by the action of the spring and dashpot. When the movement of the rail is reversed, the knuckle-joint is pulled straight, and the finger is restored to the vertical position, in readiness, as it again advances, to be again toppled over by the trigger. The valve is controlled through a lever fixed on the end of its spindle, one end of which is connected by the knuckle-joint to the finger-lever; and the other end is linked to the spring in the dashpot. The carrier-rail is shown in its extreme position to the left, and is about to move from left to right, to open the right-hand valve against the action of the spring. The spring, thus compressed, reacts outwards when released by the trip-motion, and closes the valve. The triggers, though normally stationary, are controlled by the governor, according to the position of which they are simultaneously adjusted horizontally on sliding bars, by the medium of a pair of toothed sectors. The eye of the trigger, being short comparatively, locks itself on the rod by which it is carried, when it is in contact with the trip-lever. Thus undue stress on the governor connections is obviated. The dashpot is 50 inches long internally, and about 8 inches in diameter—one dashpot serving both ends of the cylinder. The spring is helical, of $\frac{5}{8}$-inch round steel, 7 inches in diameter; in three sections, end to end, with bearing discs between the sections.

The short link of the knuckle-joint is formed with an oblong hole at the end which is connected to the lever on the valve-spindle, in order to make allowance for the expansion of the cylinder by heat.

This kind of valve-gearing has been in constant work at the rate of 106 turns per minute.

The air-pump and condenser are placed vertically, under the middle of the framing, side by side, on one base, as shown in fig. 639. They are of
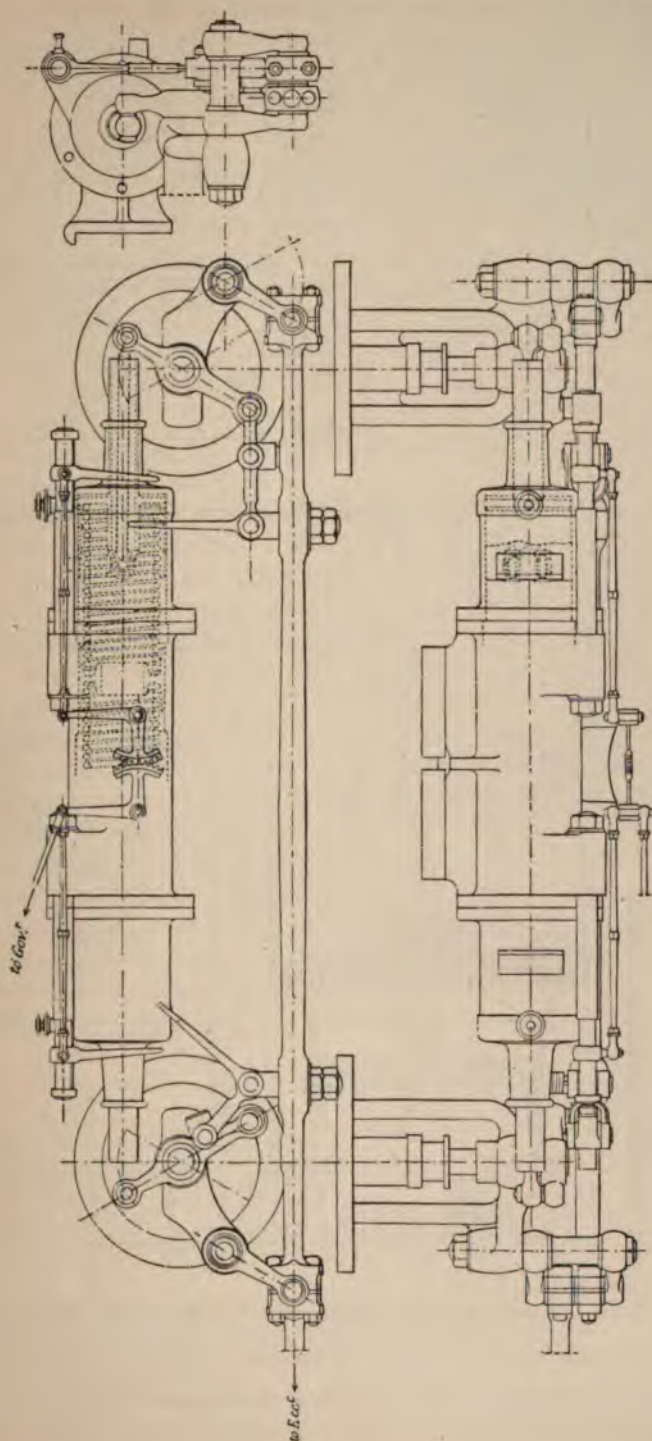
Figs. 638.—Goodfellow's Engine: Ramsbottom's Trip-gear.   Scale 1/18th.

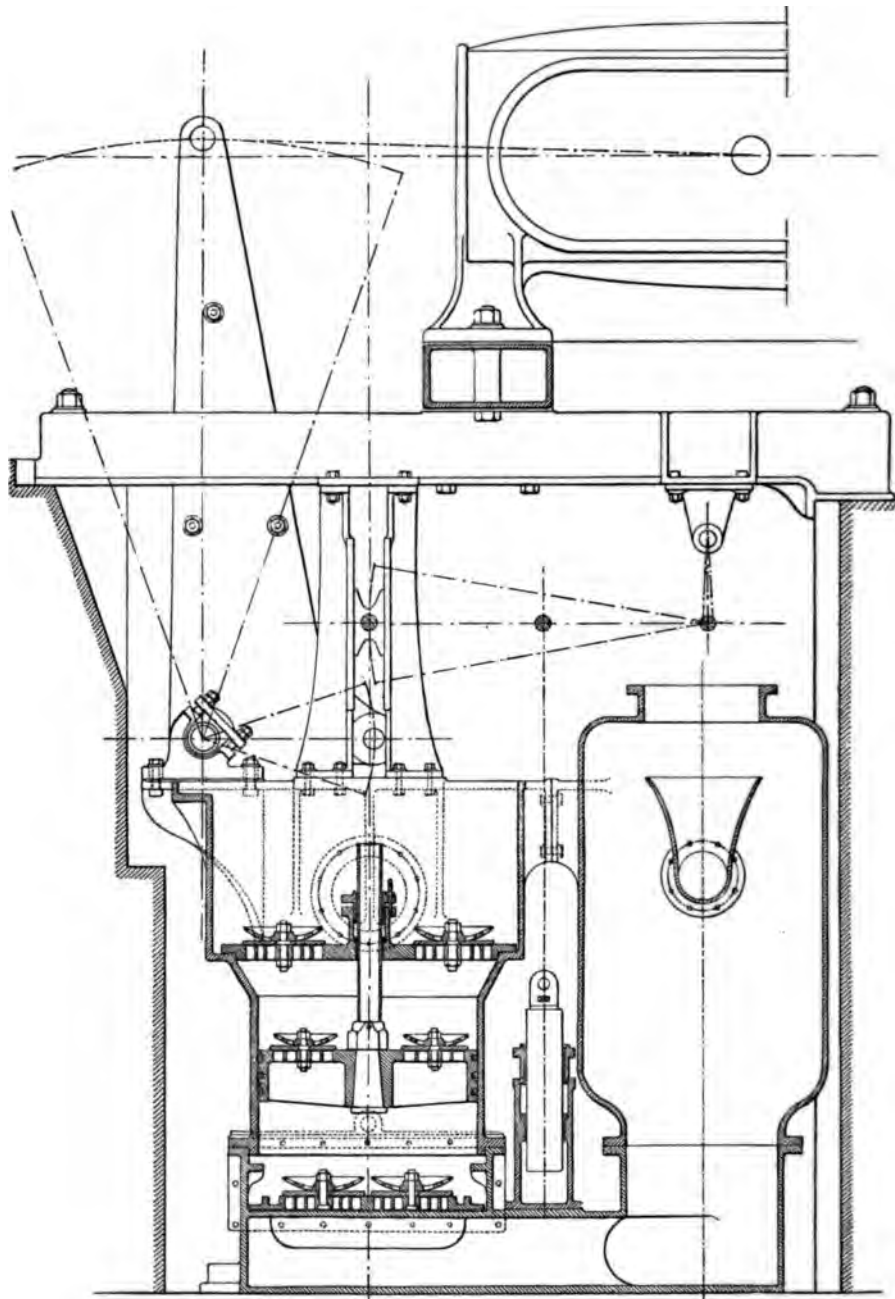cast iron, and bolted together at the upper part. The pump is 46 inches in

Fig. 639.—Goodfellow's Engine: Air-pump and Condenser. Vertical Section. Scale 1/40th.

diameter, with a stroke of 2 feet. The foot-valve and delivery-valve have each six india-rubber discs 17 inches in diameter, ¾ inch thick. The

bucket-valve has six discs 13½ inches in diameter.   The body of the pump expands into the hot-well, which is 5 feet 4 inches in diameter.   The piston-rod is of steel, 4 inches in diameter, cased in brass.   It is let into and through the bucket with an expanded end, finished with a collar at the lower end, and fastened with a nut on the upper side of the bucket.   The upper end of the bucket rod is guided by a crosshead, with slides between two pairs of cast-iron guides bolted down to the top of the hot-well, and up to two longitudinal beams of cast iron, which also support the middle part of the framing, through the medium of a transverse hollow beam of cast iron.   The pump is worked off the crosshead of the second steam-cylinder by means of a pair of bell-crank levers, each of which is constructed out of two plates of wrought iron bolted together.   The arms of the lever are 10½ feet and 3 feet in length, in the ratio of 3½ to 1, reducing the 7 feet of stroke of the steam cylinder to $(7 \div 3\frac{1}{2} =)$ 2 feet, the stroke of the air-pump.   The bell-cranks take their bearings on the hot-well, at one side, with a 5-inch gudgeon.

The condenser is 4 feet 1 inch in diameter inside, and it stands 8 feet high on the base.   The entrance for steam at the top is 2 feet in diameter; and the steam is met by the condensing water, which is delivered upwards from a 10-inch injection-pipe, expanded to 2 feet in diameter at the overflow edge.

The feed-pump is single-acting, vertical, placed between the air-pump and the condenser, and worked off the crosshead of the air-pump through a pair of radius levers.   The plunger is 7½ inches in diameter, and has a stroke of about 11½ inches.

The steam-pipe from the boiler to the regulating valve is 14 inches in diameter; thence to the cylinder it is 13 inches; and both are of ⅞-inch metal.   The exhaust-pipe from the first to the second cylinder is, as before stated, 20 inches in diameter, of 1-inch metal, and it acts as a receiver. The pipe leading to the condenser is 22 inches in diameter at the second cylinder, increasing to 24 inches at the condenser; and is of 1⅛-inch metal. The overflow-pipe from the hot-well is 18 inches in diameter.

The factor of safety is from 8 to 12.

The weights of the engine are as follows:—

	Cwts.		Tons.	Cwts.
Rope-pulley,	1560	or	78	0
Two Corliss frames,	235	or	11	15
Two pedestal ends,	270	or	13	10
Cylinders, air-pump, condenser, pipes in engine-house, &c.,	2235	or	111	15
Total weight,	4300	or	215	0

Sample indicator diagrams are shown in figs. 640.   They were taken at the speed of 50¼ turns, or 703½ feet of piston, per minute.   The steam was cut off in the first cylinder at 22.2 per cent and 24.5 per cent for the front and back ends of the cylinder; mean cut-off 23.35 per cent.   In the second cylinder steam was cut off at 22 per cent and 30 per cent; mean, 26 per

cent. The nominal ratio of expansion was in the first cylinder (100 ÷ 23.35 =) 4.28; and in the second cylinder (100 ÷ 26 =) 3.85; together, 16.48. The pressure in the boilers was 92 lbs. per square inch above the atmosphere; the mean maximum pressure in the first cylinder for the two ends was 88 lbs.; the main pressure at cut-off was 80 lbs. The mean terminal pressure by expansion, reckoned as for expansion to the end of the stroke, was $14\frac{1}{4}$ lbs. above the atmosphere; but the actual mean terminal pressure was $8\frac{3}{4}$ lbs., representing the pressure in the receiver. The mean back pressure in the first cylinder, taken as equal to the pressure in the receiver, rose to $12\frac{1}{2}$ lbs. above the atmosphere at the middle of the return stroke, and fell, slightly, to $11\frac{3}{4}$ lbs. at the point of compression. The mean maximum pressure in the second cylinder was 10 lbs. per square inch above the atmosphere, and the mean pressure at cut-off was $4\frac{1}{4}$ lbs. The mean terminal pressure reckoned for expansion was $8\frac{1}{2}$ lbs. below the atmospheric pressure, or say $6\frac{1}{2}$ lbs. absolute. The successive falls of pressure are thus summarized:—

1st Cylinder.

2d Cylinder.

Figs. 640.—Goodfellow & Matthews: Corliss Engine, Astley Mill. Indicator Diagrams.

	Absolute Pressure per sq. inch.	
Pressure in the boiler,	107	lbs.
Maximum pressure in the 1st cylinder,	103	,,
Drop of pressure between boiler and cylinder,	4	,,
Pressure at cut-off,	95	,,
Fall of pressure by wiredrawing,	8	,,
Terminal pressure by expansion to end of stroke,	$29\frac{1}{4}$	,,
Actual terminal pressure,	$23\frac{3}{4}$	,,
Drop of pressure between 1st cylinder and receiver,	$5\frac{1}{2}$	,,
Back pressure in the 1st cylinder and the receiver at half-stroke,	$27\frac{1}{2}$	,,
Maximum pressure in the 2d cylinder,	25	,,
Drop of pressure between receiver and 2d cylinder,	$2\frac{1}{2}$	,,
Pressure in 2d cylinder at cut-off,	$19\frac{1}{4}$	,,
Fall of pressure by wiredrawing of steam in 2d cylinder,	$5\frac{3}{4}$	,,
Terminal pressure by expansion to end of stroke,	$6\frac{1}{2}$	,,
Back pressure in the 2d cylinder for $12\frac{1}{2}$ lbs. vacuum, say,	$2\frac{1}{2}$	,,

The horse-power calculated from these indicator diagrams is as follows:—

Effective average pressure in 1st cylinder, front,...... 30.20 lbs. per sq. in.
Do.   do.   do.   back,...... 33.40 „   „
Do.   do.   2d cylinder, front, ... 9.75 „   „
Do.   do.   do.   back,...... 10.30 „   „

Indicator horse-power in 1st cylinder, ... 545 horse-power.
   Do.   do.   2d   do.   604   ,,
   Do.   do.   combined, ... 1149   ,,

PAIR OF HORIZONTAL TANDEM COMPOUND CONDENSING
STEAM ENGINES
FOR THE STALEYBRIDGE MILL COMPANY, STALEYBRIDGE.
CONSTRUCTED BY MESSRS. GOODFELLOW & MATTHEWS, HYDE.
PLATE IX.

(Cylinders 22 inches and 42 inches in diameter, stroke 6 feet.)

Each of these engines is designed with a Corliss frame, fig. 641, between the first cylinder and the main shaft, the second cylinder being behind the first, in line, and bound to it by the guide-bar framing of the second cylinder, fig. 642, acting also as a distance-piece. Thus the longitudinal stress of the engine is taken up by the cylinders and their direct connections, a continuous bed-plate is dispensed with, and the foundation simply supports the engine. The engines are connected to cranks at right angles on the main shaft.

The first and second cylinders are respectively 22 inches and 42 inches in diameter, with a stroke of 6 feet, driving a rope-pulley 30 feet in diameter,
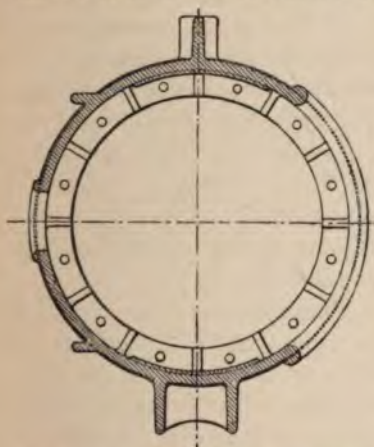
Fig. 641.—Goodfellow's Mill Engine, Staleybridge: Fig. 642.—Goodfellow's Engine, Staleybridge: Cross Section.
Section of Frame. Scale 1/24th.   Distance-piece between the Cylinders. Scale 1/24th.

grooved for 27 ropes 1¾ inches in diameter, and making 54 turns per minute. The corresponding speed of pistons is 648 feet per minute. The capacities of the cylinders are as 1 to 3.64. They are not steam-jacketed. The steam is distributed by Goodfellow & Matthews' improved Ramsbottom's trip-gear, already described. The engines are designed to cut off steam at about one-third in each cylinder, making the nominal ratio of expansion 9. With steam of 80 lbs. pressure per square inch, the normal working pressure, 1000 indicator horse-power is delivered, at a speed of

50 turns per minute; or 1062 horse-power at a speed of 54 turns per minute. The receiver pipes of the two engines are connected, and they form one receiver common to both engines.

The cylinders are of 1½-inch metal, and the covers are constructed like those of the receiver engine, page 257. The Corliss frame is of 1¼-inch metal. The pedestal is constructed similarly to that of the receiver engine. The piston-rods are of mild steel, 5 inches in diameter at the front end, 4 inches between the cylinders. The gudgeon of the crosshead is of steel, 6 inches in diameter, offering a journal 11 inches long. The connecting-rod is of wrought iron, 15 feet long, or five times the length of the crank; 5¼ inches in diameter at the crosshead end, 6 inches at the crank end, and 7½ inches at the middle. The crank-pin is of Whitworth compressed steel, with a journal 7 inches in diameter, 10 inches long. The main shaft is 19 inches in diameter at the middle, within the boss of the fly-wheel; 16 inches elsewhere, and 14½ inches at the journals, which are 27 inches long, and 12 feet 1 inch apart between centres. The rope-pulley is staked on the shaft, with four steel keys, 5½ inches wide, in each half-pulley.

The steam-valves, of the Corliss type, are 5½ inches and 9 inches in diameter respectively for the first and second cylinders; the exhaust-valves are 8½ inches and 12¾ inches. The eccentrics have 10½ inches of throw, and the motion is conveyed to the valve spindles through rocking shafts—

First Cylinder: Left-hand Front.

First Cylinder: Left-hand Back.

Second Cylinder: Left-hand Front.

Second Cylinder: Left-hand Back.
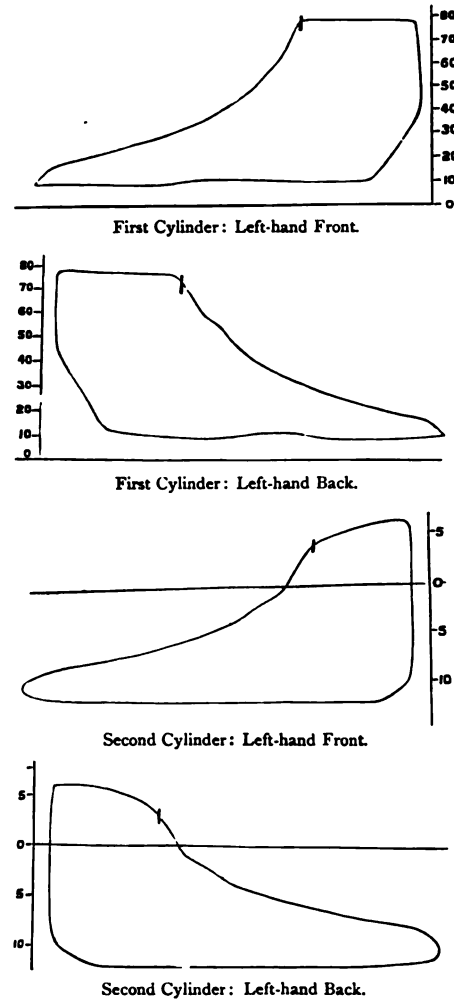
Figs. 643.—Goodfellow's Engine: Indicator Diagrams.

the full length of throw for the exhaust-valves, but reduced to 6 inches for the steam-valves.

The steam-pipes leading to each cylinder are 9 inches in diameter, of ¾-inch metal. The main pipe from the boiler is 14 inches to 13 inches in diameter at the main stop-valve. The intermediate pipes from the first to the second cylinders and the connecting pipes are 12 inches in diameter,

MAIN SHAFT AND FLY ROPE-PULLEY.
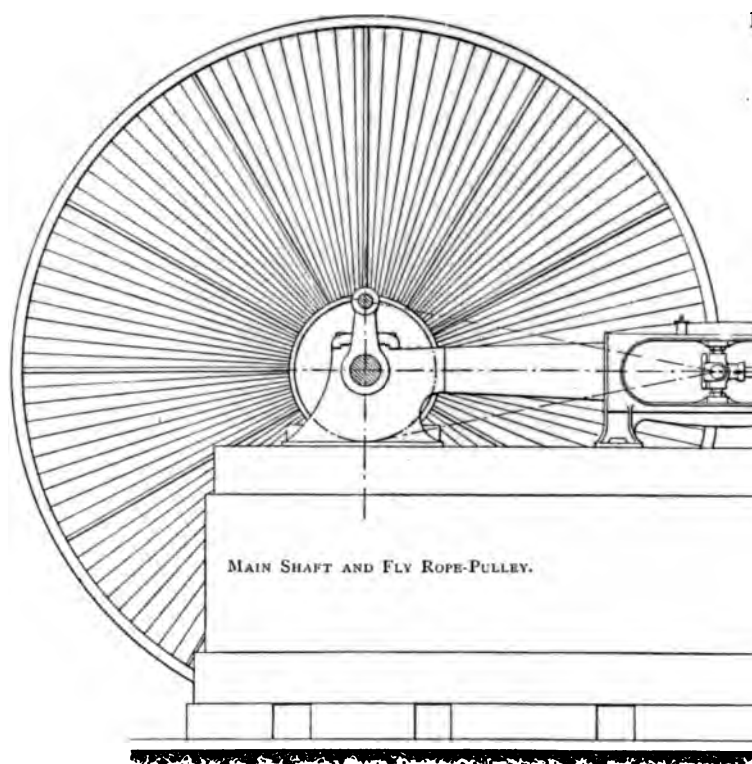
Cylinders, 22 in. and 42 in. in diameter.
Stroke of Pistons, 6 ft.
Rope Pulley for 27 Ropes, 30 ft. in diameter.
Main Shaft, 16 in. in diameter.
Speed, 54 Revolutions per minute.
Indicator Horse-power, 1062 I.H.P.

FIG. 2.—PLAN.

PLATE IX.
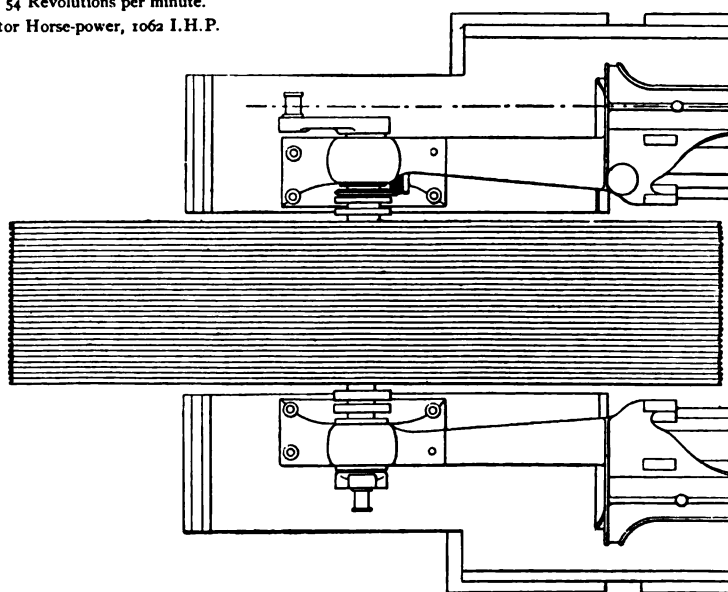
TAL COMPOUND TANDEM CONDENSING STEAM ENGINES,

MESSRS. GOODFELLOW AND MATTHEWS, HYDE, NEAR MANCHESTER,

FOR THE STALEYBRIDGE MILL COMPANY, STALEYBRIDGE.

SCALE, 1-96TH, OR ⅛ INCH = 1 FOOT.

FIG. 1.—SIDE ELEVATION.

1st CYLINDER.   2nd CYLINDER.
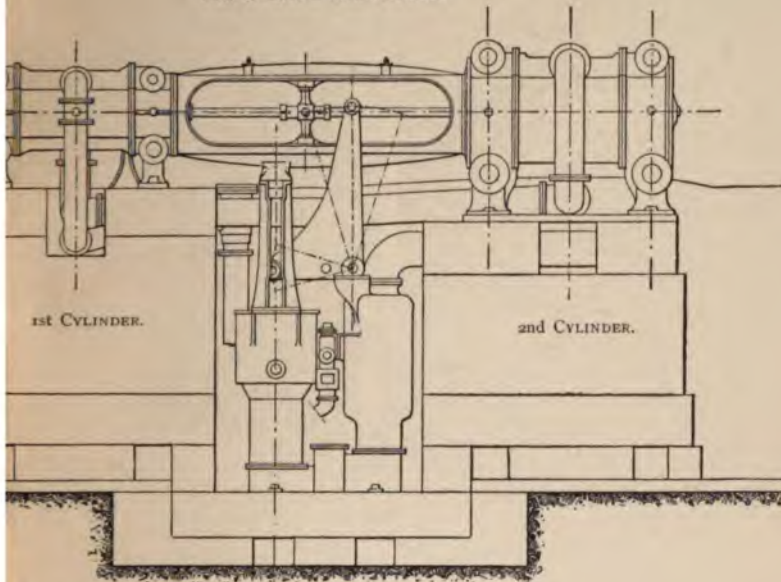
CONDENSER AND AIR-PUMP.
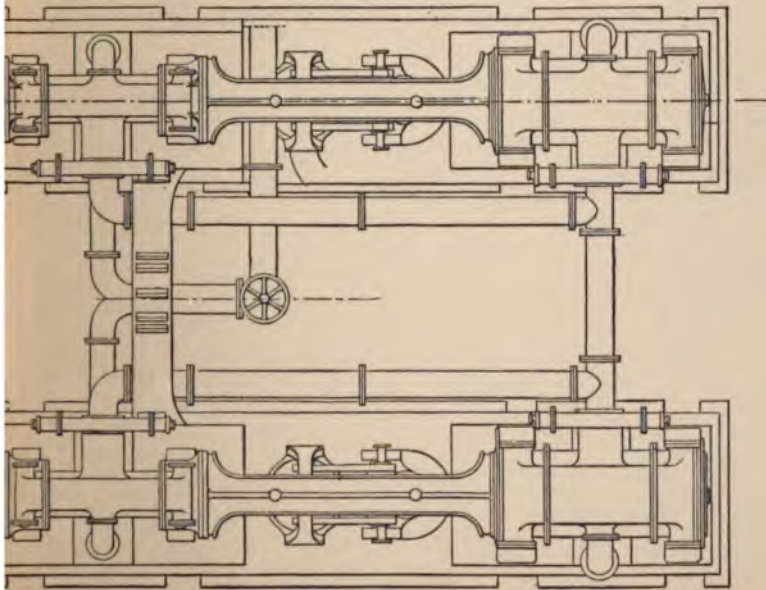
of ⅞-inch metal. The pipes leading from the second cylinder to the condenser are 15 inches in diameter at the cylinder, increasing to 16 inches at the condenser, of 1-inch metal.

Sample indicator diagrams, taken from the left-hand engine, when the engines were worked at full power, are shown in figs. 643. The principal quantities were as follows:—

Mean cut-off in the first cylinder...... 32 per cent; nominal ratio, 3.1
    Do.   second do. ...... 26½ ,,   do.   3.8
Total nominal ratio of expansion 11.78
Pressure in the boiler above the atmospheric, per square inch... 80 lbs.
Maximum pressure in the cylinders,   do.   ... 77½ ,,
Back pressure in the first cylinder, or in receiver pipes, do. ... 9½ ,,
Maximum pressure in second cylinder above the atmosphere... 6¼ ,,
Average vacuum, 11¾ lbs., or above absolute vacuum, say..... 3¼ ,,

The indicator horse-power was as follows:—

	1st Cylinder.	2d Cylinder.	Together.
Right-hand engine	266.3 H.P.	272.0 H.P.	538.3 H.P.
Left-hand do.	267.8 ,,	256.2 ,,	524.0 ,,
Totals	534.1 ,,	528.2 ,,	1062.3 ,,

Chapter XXVII.—HORIZONTAL TANDEM COMPOUND STEAM ENGINE of 900 Horse-power.

CONSTRUCTED BY MESSRS. TIMOTHY BATES & CO. (POLLITT & WIGZELL), SOWERBY BRIDGE.

PLATE X.

(Cylinders 27 inches and 46 inches diameter, 5½ feet stroke.)

The compound horizontal engines on the system of Messrs. Pollitt & Wigzell, are laid on a continuous iron bed, on one centre-line. The first and second cylinders are laid end to end, and are directly bolted together—the second or low-pressure cylinder behind the first or high-pressure cylinder. The condenser and air-pump are laid behind the second cylinder, and the air-pump is worked directly from the second piston, by a rod through the back of the cylinder. The first and second cylinders are connected to one crosshead—the first by one piston-rod, with a forked end, between the forks of which the connecting-rod takes its bearing; and the second by two piston-rods, one at each side, flanking the first cylinder, and cottered to the guide-blocks on the ends of the crosshead. The guide-blocks are of wrought iron, fitted with cast-iron slippers. The cylinders are three-ported, with an ordinary slide-valve to each—the spindles of the two valves being connected, and worked by one eccentric on the main shaft. The valves are set so as to cut off at half-stroke in the first cylinder, and at three-quarter stroke in the second cylinder. Cut-off plates, adjustable by right and left hand screws, on a separate spindle, as in Meyer's gear, work on the back of the first slide-valve, to vary the expansion. They are driven

by means of a separate eccentric, and they are adjustable by hand whilst the engine is in motion. In more recent designs, the cut-off by the expansion-valves is regulated automatically by the governor. For this purpose an intermediate driving-band is employed, which, in the normal condition of uniform speed, runs on a loose pulley. When a change of speed occurs, the belt is shifted by the action of the governor to one of two fast pulleys, by means of which a worm is actuated, and through the worm-wheel turns the screws and separates or approximates the cut-off plates, as the case may require, on the back of the first slide-valve. The cylinders are not steam-jacketed; they are covered with hair-felt, and lagged with polished bay wood.

The condenser is a cubical casting, into which the steam is exhausted at the top, and in which it is met by a jet of cold water brought in at one side, and directed upwards. The resulting water and vapour are taken up by the air-pump, which is horizontal within and at the bottom of the condenser, and delivered into a compartment partitioned off at the far end of the condenser, whence it is conducted by an overflow pipe. The air-pump is single-acting; the far end of the barrel is fastened to and forms part of the partition; and it is perforated for numerous india-rubber disc-valves, which open outwards to the overflow compartment. There are no other valves about the pump. The "bucket" is, in fact, a piston, and the inflow of water and vapour to the barrel takes place through a number of openings in the barrel, which are traversed by the piston in each stroke. As the piston is withdrawn to the near end of the barrel, clearing the openings, water and vapour rush through the openings into the barrel, impelled by the unbalanced pressure in the condenser, as well as by gravitation. In describing its advancing stroke, the piston drives out the water and vapour before it, through the disc-valves at the end, into the outflow compartment. During the return or receding stroke, the valves are closed, and a vacuum is again formed, until the piston, on its outward stroke, passes the openings, when, as before, the water and vapour flow in. It has been found necessary, for the proper working of the air-pump, to place an annular cover or casing over the openings through the barrel. Such a shield appears to operate in regulating the inflow, and preventing or at least softening concussion, caused by the air and water rushing in.

All the brasses throughout the engine are of phosphor-bronze, and all working joints are adjustable on the screw-and-wedge system.

The whole of the engine is laid on a continuous cast-iron bed-plate, in three pieces, bolted together, and bolted down to the foundation.

The unit of power adopted by Messrs. Bates & Co. is an allowance of 23 square inches of area of the second cylinder per nominal horse-power for condensing engines; and 12 square inches of area of cylinder per nominal horse-power for non-condensing engines.

A compound horizontal engine, of 900 indicator horse-power, constructed for Messrs. W. Rouse & Co., is shown in elevation and plan, Plate X. The first cylinder is 27 inches in diameter, and the second is 46 inches, with

a stroke of 5½ feet; making 74½ turns per minute, equivalent to a speed of piston of 819½ feet per minute. The areas of the pistons are as 1 to 2.90; and, the steam being cut off at half-stroke in the first cylinder, the total nominal expansion-ratio, not reckoning for clearance, is (2 × 2.90 =) 5.80. The piston-rods are of steel, and are 4 inches in diameter. The crosshead bearing is 6½ inches in diameter and 8½ inches long. The connecting-rod is of wrought iron, and is 12 feet 6 inches long, or 4.54 times the length of the crank. It is 5 inches in diameter at the crosshead, 6 inches at the crank end, and 7 inches at the middle. The main shaft is of wrought iron, 12⅝ inches in diameter at the bearings, which are 24 inches long; enlarged to a diameter of 18 inches to take the fly-wheels. The main bearing is cast with the bed-plate, and the brasses are in three pieces, being adjustable by a wedge-action. The crank is of wrought iron; and the crank-pin is of steel, having a journal 8½ inches in diameter and 10½ inches in length. The fly-wheel is 17 feet in diameter, and is made as two wheels, each of which is cast in two halves, which are bolted together. The rims are turned for two belts 22 inches wide, and two belts 16 inches wide. The whole fly-wheel weighs 30 tons.

The air-pump is 24 inches in diameter, with a stroke of 5½ feet. The governor is not automatic; that is to say, it does not act on the valve-gear.

The following are particulars of a similar engine of 1200 indicator horse-power, according to the more recent practice of the constructors, for the Palm Mill Company, Oldham. The first and second cylinders are 30 inches and 51 inches in diameter respectively, with a stroke of 5½ feet: the areas of the cylinders being in the ratio of 1 to 2.89. The diameter, 30 inches, of the first cylinder is adopted in view of moderate pressures of from 60 lbs. to 70 lbs.; but for 90 lbs. pressure in the boiler, a diameter of 27 inches is preferred. The expansion-valves are controlled automatically by the governor, in the manner already explained. The pistons are fitted with steel coil-packing and with steel piston-rods, 4¾ inches in diameter. The second piston is 14 inches thick, of 1¼-inch metal, cast in one piece, hollow, with a junk-ring. The connecting-rod is of wrought iron, 6 inches in diameter at the crosshead, 7 inches at the crank end, and 8½ inches at the middle. It is 12½ feet long, or 4.55 times the length of the crank. The crank is of wrought iron, with a steel crank-pin, 9 inches in diameter and 12 inches long. The main shaft is of Whitworth's fluid-compressed steel, 13½ inches in diameter at the journals, which are 30 inches long, and 19 inches at the fly-wheel. The fly-wheel is 20 feet in diameter, with 10 arms, and is turned at the rim for 36 ropes 1⅝ inches in diameter; it is built up as two wheels for 18 grooves each. The air-pump is 24 inches in diameter. The normal speed of the engine is 70 turns per minute, equivalent to 770 feet of the pistons per minute. The steam-pipe is 9 inches in diameter, the intermediate pipe between the cylinders is 11 inches, and the exhaust-pipe is 13 inches. The pressure in the boiler is 90 lbs. per square inch. The total weight of the engine is 125 tons, including 45 tons, the weight of the fly-wheel; and 16 tons, the weight of the bed-plate. The price is £3000, or £24 per ton.

In the opinion of Messrs. Timothy Bates & Co., steam-jackets are not of advantage for compound engines, except that a little benefit may be gained by jacketing the second cylinder. But by superheating the steam exhausted from the first cylinder on its passage to the second cylinder, an economy in fuel of from 10 per cent to 15 per cent may be effected, though the benefit is neutralized by the first cost and the maintenance of the plant required for the purpose. They give, for example, the results of one month's working of one of their engines, at the works of Messrs. Crossley & Sons, Halifax, indicating 500 horse-power. The cylinders are 23 inches and 43 inches in diameter, with a stroke of 5 feet, making 68 turns per minute, or a speed of piston 680 feet per minute, with 60 lbs. steam in the boiler. The results show a consumption of 15.27 pounds of water, and 2.18 pounds of coal per horse-power, with the use of the interheater of exhaust steam; and 18 pounds of water and 2.34 pounds of coal per horse-power, without the use of the interheater. These rates of consumption include the whole of the coal and water necessary at a cotton-mill, including what is consumed for warming, &c.

Again, they report the results of four weeks', or 224 working hours' trial of an engine of their ordinary type, at Prospect Mill, Sowerby Bridge, owned by Messrs. C. E. & F. Ramsden. The cylinders were 23 inches and 43 inches in diameter, having areas as 1 to 3.50, with a stroke of 5 feet. The average power indicated was 500 horse-power. The coal, Liversedge slack, consumed was 112 tons, or $(112 \times 2240 \div 224 \div 500 =)$ 2.24 pounds per hour per horse-power, which includes the steam for warming the mill, raking and damping up the fires each night, and the week ends. The town's water, at 45° temperature, was used for the feed. For a period of eight hours, 896 gallons per hour were consumed, or $(896 \times 10 \div 500 =)$ 17.92 pounds per horse-power.

In another trial, lasting 8 hours, for the production of 500 horse-power, 3 tons 7 cwts. 96 lbs. of coal was consumed, or 1.9 pounds per hour per horse-power; and 779 gallons of water per hour, or $(779 \times 10 \div 500 =)$ 15.58 pounds per hour per horse-power. Two boilers, 7 feet in diameter, 28 feet long, generating steam of 60 lbs. pressure per square inch, with Green's economizer of 196 pipes, were used for these trials.

At the same mill, the consumption of coal for six months of the year 1885 was at the rate of 31 tons per week, for 550 indicator horse-power, or $2\frac{1}{4}$ pounds per hour per horse-power for all purposes.

Sample indicator diagrams were taken from the front end of the first cylinder, and the back of the second cylinder, at Prospect Mill. The initial pressure in the first cylinder is 54 lbs. per square inch above the atmosphere; but the steam has been wiredrawn during the period of admission, and has fallen to a pressure of 40 lbs. at half-stroke, when it was cut off. The drop of pressure between the cylinders is from 10 lbs. above the atmosphere at the end of the stroke of the first cylinder, to $7\frac{1}{4}$ lbs. in the second cylinder, or a drop of $2\frac{3}{4}$ lbs.; and at half-stroke returning, there is a difference of pressure or drop of $5\frac{1}{4}$ lbs. The drop is due chiefly to the

Diameter of 1st Cylinder, 27 in.
  ,,   2nd   ,,   46 ,,
Stroke of Pistons, 5½ ft.
Speed, 74½ Revolutions per minute.
Indicator Horse-power, 900 H.P.
Air-Pump, 24 in. in diameter.
Main Shaft, 12⅝ in. in diameter at
    journals.
Flywheel, 17 ft. in diameter; 30 tons.
Total weight, about 90 tons.

FIG. 1.— LONG

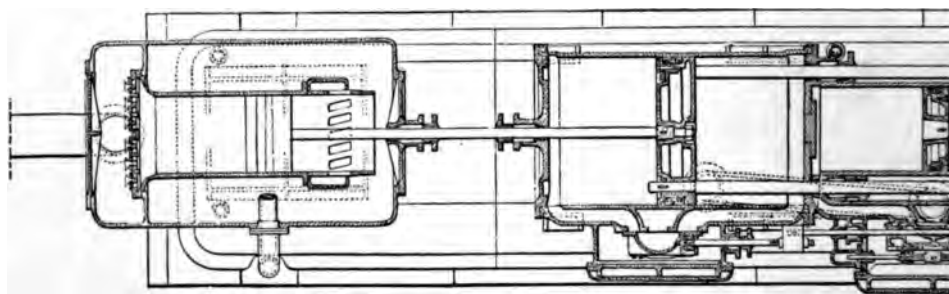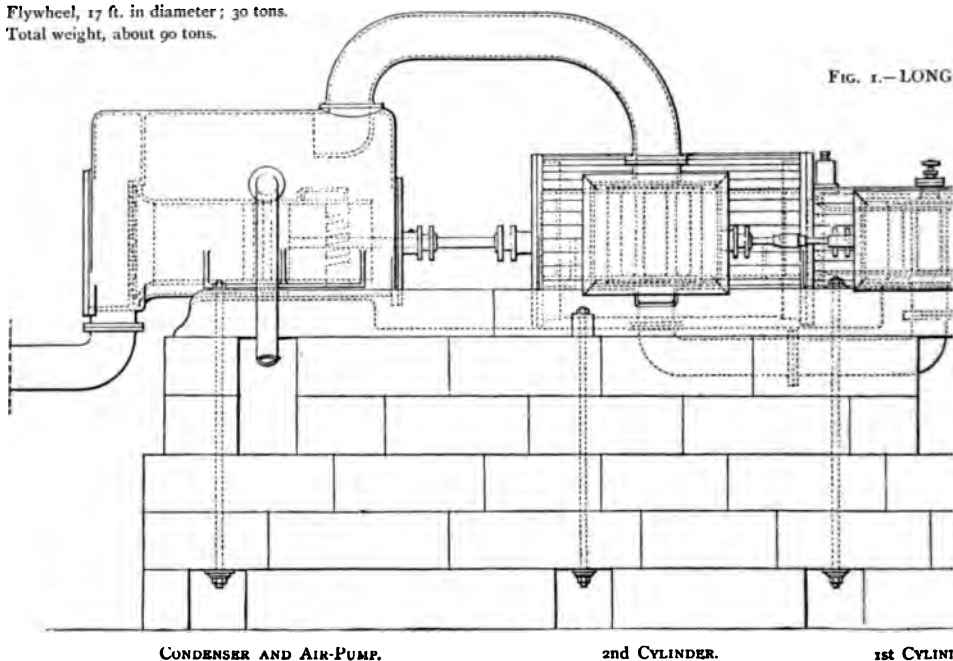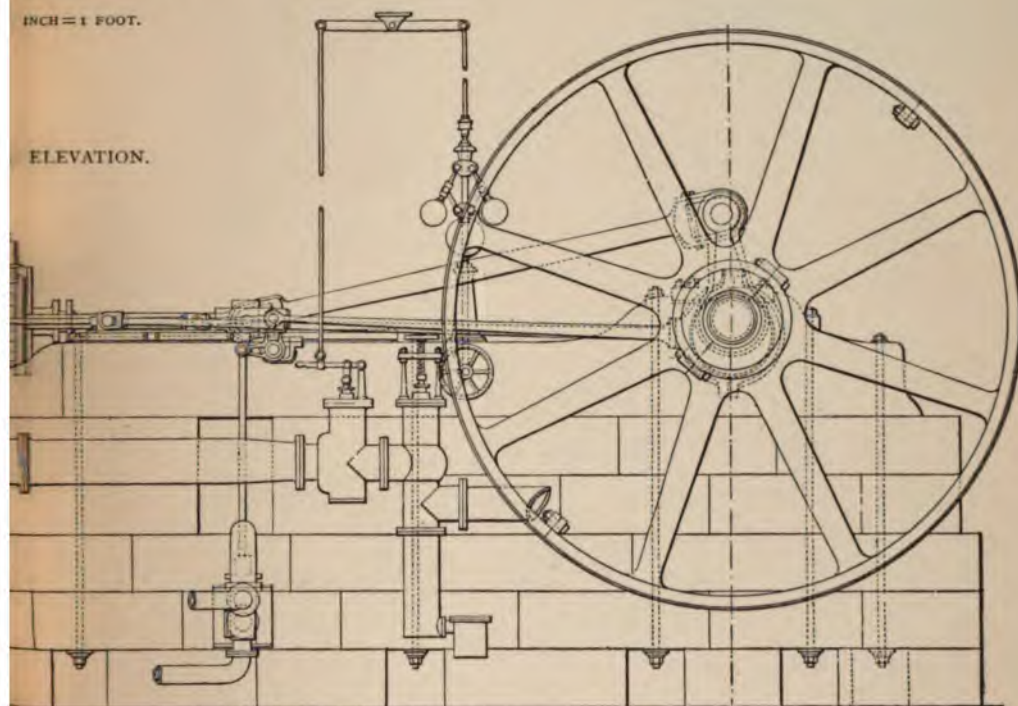CONDENSER AND AIR-PUMP.   2nd CYLINDER.   1st CYLINI

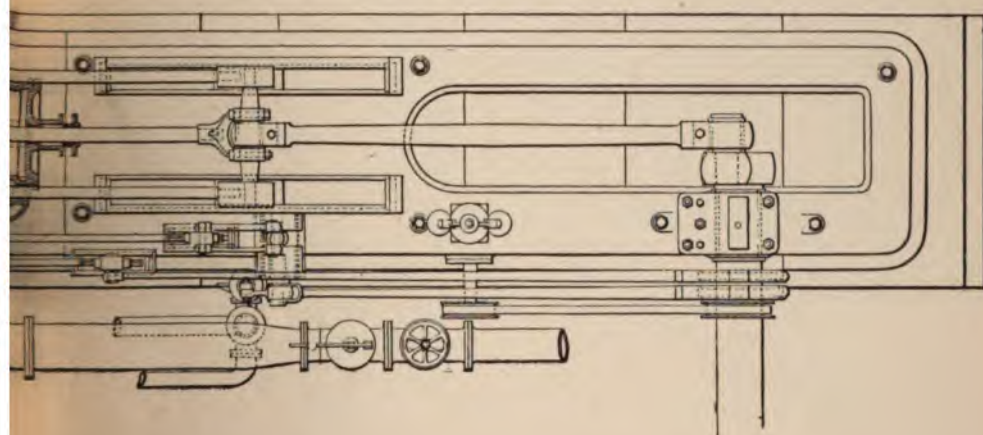FIG. 2 —SECTIONAL PLAN.

PLATE X.

POUND STEAM ENGINE.

D. (POLLITT AND WIGZELL), SOWERBY BRIDGE.

INCH = 1 FOOT.

ELEVATION.

MAIN SHAFT.

length and capacity of the intermediate pipe, and other passages, with the valve-chest of the second cylinder. The pressure in the boiler was 60 lbs. per square inch, and the speed was 68 revolutions, or 680 feet of piston per minute.

A compound engine constructed on the same system, erected at Deptford Bridge Mills, was tested in January, 1886, for indicator power and consumption of fuel. The cylinders are respectively 20 inches and 37 inches in diameter, with a stroke of 3 feet. The fly-wheel is 12 feet in diameter, turned at the rim for seven ropes 1½ inches in diameter, and it weighs 14 tons. The shaft is 8 inches in diameter at the journals. The air-pump is 14 inches in diameter. The steam is condensed in a surface-condenser of 800 square feet of surface; with a double-acting 7-inch circulating pump, worked directly from the piston of the second cylinder. The condenser has cold-drawn brass tubes ¾ inch in diameter outside, 5 feet in length between the tube-plates, and secured to the tube-plates with wood ferules.

The trial lasted 24 hours, the engine making from 92 to 93 turns, or from 552 feet to 558 feet of piston per minute. The indicator diagrams were remarkable for the wiredrawing of the steam during admission into the first cylinder. The initial pressure of admission was about 64 lbs. per square inch above the atmosphere, and the pressure fell to 34 lbs. at half-stroke, at which point the steam was cut off. The wiredrawing is measured by a fall of pressure of 30 lbs. These diagrams were taken on the second day. Those taken on the first day were similar, but of lower pressures—52 lbs. initial, wiredrawn to 25 lbs. at half-stroke. The average effective pressures on the second day were $((35.4+36)\div2=)$ 35.7 lbs. per square inch in the first cylinder; and $((6.97+7.10)\div2=)$ 7.04 lbs. per square inch in the second cylinder. The vacuum in the cylinder was 12¼ lbs. on the second day, and 12½ lbs. on the first day. The indicator horse-power on the second day was, in the first cylinder, 189.5, and in the second, 127.2 — together, 316.7 horse-power. On the first day it was (141.3 + 108.6=) 249.9 horse-power. The mean power for the two days was $((316.7+249.9)\div2=)$ 283.3 horse-power. The coal, good Welsh, consumed during the 24 hours weighed 4 tons 16 cwts., or 4 cwts. per hour, or 1.58 pounds per horse-power per hour. The boiler is tubular; there is no economizer.

It may be added that steam engines of the general design of Plate X. have more recently been constructed by Messrs. Timothy Bates & Co., with piston-valves throughout, and an automatic cut-off worked direct from the governor. These valves will be described in a subsequent chapter on triple-expansion steam engines.

PUMPING STEAM ENGINES.

The pumping of water from mines, or for the service of towns, or for other purposes, has been, until about thirty years ago, almost universally performed by direct lifts. The extreme variety of work and duty, under differing conditions, involves, of course, a variety of proportions, chiefly of the ratio of the diameter of the steam cylinder to that of the plunger-pole of the pump. The Fowey Consols engine has an 80-inch cylinder, with 10 feet 4 inches of stroke. The pump has 9 feet 3 inches of stroke, drawing six lifts—that is to say, pumping by six successive stages. Three of the plunger-poles are 15 inches in diameter, one 13½ inches, and two 12 inches; the diameters of the plunger-poles·averaging about one-sixth of that of the steam cylinder. On the contrary, the pole of the " Victoria" pumping engine at the East London Water-works, having a 100-inch cylinder, is 50 inches in diameter, or half of that of the cylinder. Obviously, the ruling element is the " head" against which the engine is to work: the greater the head, the smaller is the pole in proportion to the cylinder, under like circumstances.

Chapter XXVIII.—CORNISH PUMPING STEAM ENGINES.

HEBBURN CORNISH PUMPING ENGINE.

(Cylinder 70 inches, stroke 10 feet.)

The Hebburn Cornish Engine was described by Mr. J. B. Simpson, in 1870, as the first of the Cornish pattern introduced into the Newcastle Colliery district at Hebburn, for the Tyne Coal Company.[1] The engine is rated as of 250 nominal horse-power, giving about 20 circular inches of piston per horse-power. It has a 70-inch cylinder, with a stroke of 10 feet; and a stroke of 8 feet in the pit. The beam is 30 feet long. The steam-valve is 12 inches in diameter, equilibrium-valve 13 inches, exhaust-valve 16 inches, injection-valve 5½ inches. The air-pump is 2 feet 11 inches in diameter, with a stroke of 4 feet 4 inches.

The cylinder is steam-jacketed, and the jacket is coated with ashes or clay, 12 inches thick; and over this a covering of brickwork, felt, and wood lagging, in succession. The condensed steam from the jacket is drained back into the boilers.

Three plungers or force-pumps, and one short bucket-lift in the pit, are connected to the engine, as follows:—

[1] See Mr. Simpson's paper " On the Duty of Cornish and other Pumping Engines for Draining Mines," in the *Transactions of the North of England Institute of Mining and Mechanical Engineers,* vol. xix. page 201; 1869-70.

	Length.	Diameter of Pump.
First plunger set.................	38 fathoms.	21 inches.
Second ,, ...	40 ,,	18½ ,,
Third ,, ...	36 ,,	18½ ,,
Fourth bucket-lift	6 ,,	18½ ,,
	120 ,,	

The weight of the column of water is about 40 tons. The spear-rods are of Vancouver pine, 18 inches square for the upper two sets, 12 inches for the third, and 8 inches for the bucket-lift. Steam was supplied from four boilers, 34 feet long, 6¾ feet in diameter at the fire end, 5¾ feet at the chimney end, with a 4¼-feet furnace-tube, reduced to 2¼ feet at the end.

The boilers and pipes are protected so that there is the least possible loss of heat by radiation. The boilers are coated with 12 inches of clay, and are roofed over. Three boilers in steam are sufficient to drive the engine at the rate of nine strokes per minute.

Results of trials of this engine, with from one to three plunger-pumps for increasing depths, and the bucket-pump, are as follows:—

Hebburn Cornish Pumping Engine.

No. of Trial and Date.........	1. May, 1869.	2. Aug., 1869.	3. April, 1870.	4. July, 1870.	5. July, 1870.
Length of sets, fathoms	P 38 B 46	P 38 P 40 P 18	P 38 P 40 P 36	P 38 P 40 P 36 B 2	P 38 P 40 P 36 B 6
Total length—fathoms......	84	96	114	116	120
Strokes per minute	7	8.44	7.93	7.03	7.19
Gallons per minute..............	644	987	935	829	848
Small coal per hour..............	458 lbs.	758 lbs.	740 lbs.	541 lbs.	508 lbs.
Indicator horse-power...........	145.4	182	—	184.5	—
Effective horse-power	92	150	265.46	149.16	154.73
Do. do. per cent..	63	82.5	—	80.7	—
Coal per indicator horse-power per hour.......................	3.14 lbs.	4.35 lbs.	—	2.93 lbs.	—
Do. effective do.	4.9 lbs.	5 lbs.	4.4 lbs.	3.6 lbs.	3.3 lbs.
Duty in millions of pounds per 112 lbs. of coal..............	46.51	44	49.78	61.28	67.72
Cost per year of 100 effective horse-power; coal at 4s. per ton	£388	£395	£349	£283	£257

The average consumption of coal per effective horse-power, of some of the largest pumping engines in Cornwall, has been ascertained to be about 3 pounds. An engine at Wheal Vor has an 85-inch cylinder, having 9 feet of stroke; with 12 sets of pumps, one above another, as follows:—

	Fathoms.	Diameter of Pump.
1 plunger	40	15 inches.
1 do.	30	15 ,,
1 do.	30	15 ,,
1 do.	30	13½ ,,
1 do.	20	13½ ,,
1 do.	20	13½ ,,
1 lift	10	8 ,,
1 do.	10	8 ,,
	190	

The shaft is vertical for a depth of 70 fathoms. Below this depth it follows the direction of the vein, which is much inclined. Several balance-beams are employed to counteract the extra weight and friction, taking off about 50 tons of the weight. At a depth of 147 fathoms, a horizontal drift goes 480 feet to another shaft. On this drift a spear works two 8-inch plunger-pumps on 80 fathoms, and two 8-inch lift-pumps on 36 fathoms. The engine makes 6 strokes per minute, and is worked by three boilers, consuming 6¼ tons of coal per day, or less than 4 pounds per effective horse-power per hour.

The 100-inch Cornish pumping engine, at the same mines, now removed, made 5¾ strokes per minute, and gave a duty of 70 millions. Fourteen lifts were worked by it, together 381 fathoms long; by which 16,266 gallons of water, weighing 72 tons, was lifted at each stroke. The total weight of the mass put in motion at each stroke, including the rods and their counter-balance, amounted to 834 tons. The following are details of pit work:—

Plunger.	Fathoms.	Diameter of Pump.
First	28	16 inches.
Second	35	15 ,,
Third	35	15 ,,
Fourth	34	15 ,,
Fifth	40	15 ,,
Sixth	24	15 ,,
Seventh	30	15 ,,
Eighth	20	15 ,,
Ninth	22	15 ,,
Tenth (bucket lift)	22	16½ ,,

In the 174 fathoms level, there are 624 feet of flat rods, which are connected with spear-rods in another shaft, and go down dry to a depth of 236 fathoms, at which level the water goes back to the main shaft. Two sets of pumps are worked in this way:—

12 fathoms of 11½-inch bucket-pump.
28   do.   11½   do.   do.

The spear-rods are double from the surface to a depth of 130 fathoms, 16 inches square at the top, diminished to 12 inches at this depth. From

this point downwards the rod is single, 16 inches square, diminishing to 12 inches square at the bottom.

The counterpart of this engine was erected at Wallsend, having a 100-inch cylinder, rated as of 500 nominal horse-power; stroke, in the cylinder and in the pit, 11 feet. The weight of the cylinder, nozzles, &c., is 46 tons. The main beam 36 feet long, 7 feet deep at the main centre, weighs 40 tons. The steam-valve is 15 inches in diameter, equilibrium-valve 21 inches, exhaust-valve 27 inches, air-pump 3 feet 9½ inches. The pumps are 25 inches in diameter; and, at the rate of 8½ strokes per minute, they raise 2000 gallons per minute from a depth of 124 fathoms—about 450 effective horse-power. The spear-rods are 24 inches by 20 inches.

CORNISH PUMPING STEAM ENGINE, EAST LONDON WATER-WORKS.

The Cornish pumping engines of the East London Water-works have already been noticed, vol. i. p. 508, and results of performance given. One of them, the "Victoria" engine, is represented by figs. 644 and 645. The cylinder is 100 inches in diameter, and is capable of making a stroke of 12 feet. The beam is 36 feet long between the end centres, and is 7½ feet deep at the middle. The pole or plunger is 50 inches in diameter, having the same stroke as the piston. The plunger is loaded with iron weights sufficient to counterpoise the pressure of a hydrostatic column, in a stand-pipe, which is the measure of the pressure created in the central station to put in action the supply of water to the eastern districts of London. The pole-case is 68 inches in diameter; with supply and discharging mains up-wards of 4 feet in diameter. An air-vessel, the position of which is indicated by dot-lining, is placed on the discharging main, to equalize the head of pressure. The steam from the boiler is admitted to the upper side of the piston and worked expansively, forcing it down, and lifting the weighted pole of the pump at the other end of the beam. The impetus communicated to the moving mass by the initial charge of steam, together with the ex-pansive force of the steam, carries it through the remainder of the stroke,— the velocity of the piston being gradually retarded till the end of its course, while the resistance remains the same. The uplifting of the pole causes a vacuum in the pump into which the water flows through the suction-valve. At the end of the steam-stroke the exhaust-valve closes, and the equilibrium-valve opens, admitting the steam above the piston to the under side, and the pressure is equalized above and below the piston. Then the weighted pole descends by the action of gravity and forces the water out of the pump, at a speed depending on the engine-power and the rate at which the water is being drawn away or consumed. Just before the piston reaches the top of the cylinder, the equilibrium-valve closes, and the portion of steam left above the piston is compressed, forming a cushion to bring the piston and connections to a state of rest. The outlet-valve from the lower side of the piston to the condenser is then opened, and after it the steam-valve, when fresh steam from the boiler is admitted above the piston, and it performs the next descending stroke—the "indoor" stroke. The speed of the engine

is regulated by an adjustable "cataract," a mechanical appliance connected with the gearing, which is set in action at every stroke of the engine, and is adjusted to expend itself, and, at a suitable interval, to release the detents by which the movements of the valve-gearing are controlled. The detents being disengaged the steam-valve opens, by means of the action of the
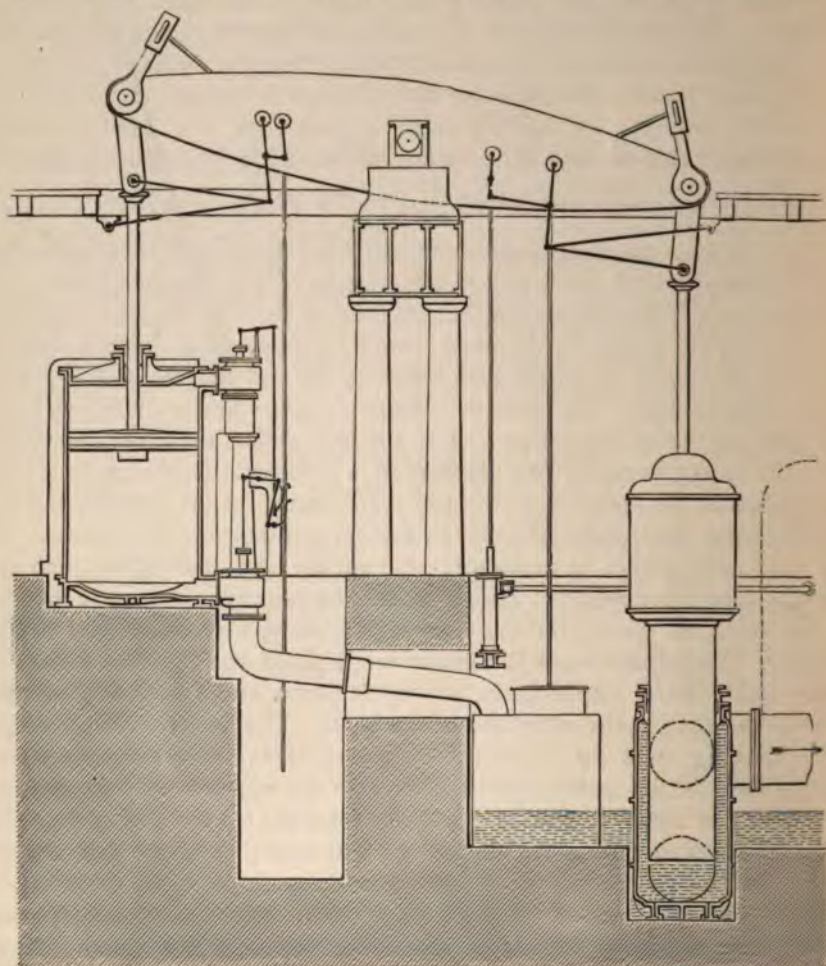

Fig. 644.—East London Water-works: Victoria Pumping Engine. Sectional Longitudinal Elevation. Scale 1/140th.

treadle-weights, and the steam is admitted for the next steam-stroke. All the valves fall open by means of the treadle-weights, and they are closed by means of tappets on a plug-rod which hangs from the beam.

The stroke of the engine is liable to variation in length, according to variations of resistance, even, in the case of the East London Water-works, to the extent of some inches in the course of the day. In order to fix a maximum limit to the length of the stroke, bumpers or catch-pieces are provided at each end of the engine to restrain it from exceeding the

maximum course at either end.   For this purpose, thick plates of india-rubber under hardwood blocks are employed.

The indoor stroke is performed in these engines at the average velocity of from 500 to 600 feet per minute.   When steam is cut off at one-fourth,
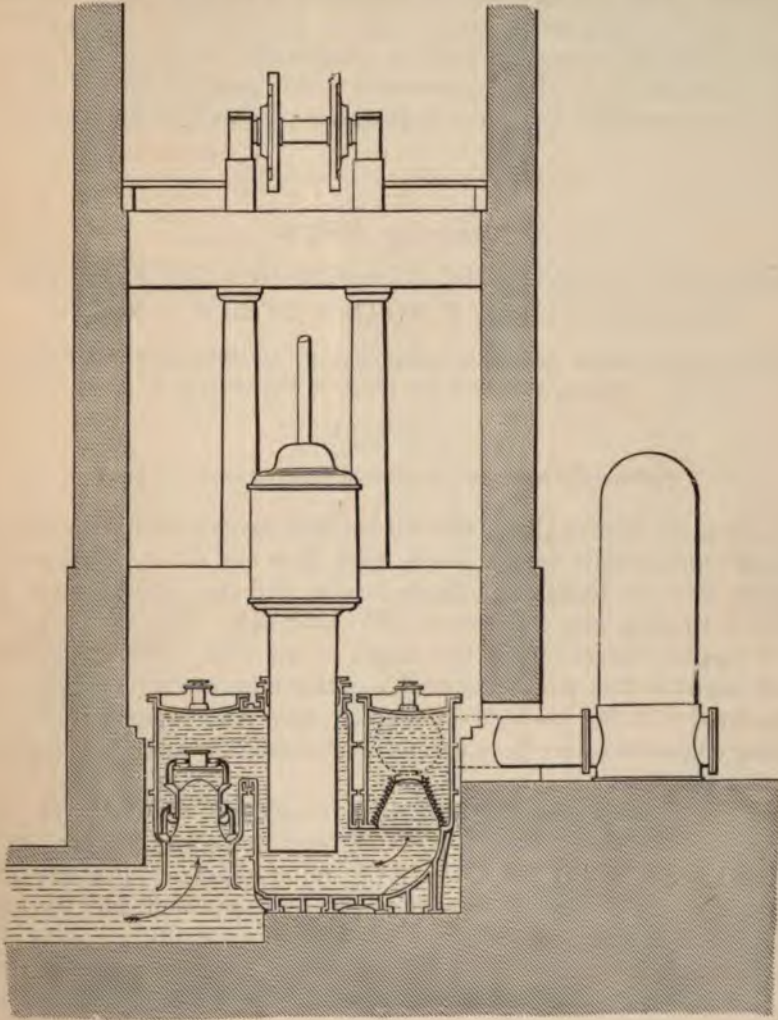

Fig. 645.—East London Water-works: Victoria Pumping Engine. Sectional Transverse Elevation. Scale 1/140th.

a 10-feet stroke may be performed in one second; and cutting off at one-third, in 1⅓ seconds.   In mining engines, 2 or 2½ seconds may be required for a 10-feet stroke.   As the chamber of the pump has to be filled during the indoor stroke, the dimensions of the suction-valve are liberal, and two such valves are sometimes employed.   As it is absolutely necessary for good working that the suction-valves close at least as soon as the indoor stroke is completed, the lift and loading of the valves must be carefully adjusted.

Direct-acting or bull-engines also are constructed, in which the cylinder is inverted over the pump, and the piston is directly connected to the plunger. Compound direct-acting engines on the Davey system are much employed; also the Worthington system of direct-action pumps in pairs interacting. Direct-acting horizontal pumping engines, with crank-shaft and fly-wheel motion, are in general use on the Continent. Rotative beam pumping engines, simple as well as compound, in which the length of stroke is exactly defined by connection with a crank-shaft and fly-wheel, are also manufactured for water-work service, as well as for the lifting of sewage.

CHAPTER XXIX.

VERTICAL COMPOUND CONDENSING DIFFERENTIAL DIRECT-ACTING PUMPING STEAM ENGINE.

DESIGNED BY MR. HENRY DAVEY; CONSTRUCTED BY MESSRS. HATHORN, DAVEY, & CO., LEEDS, FOR THE ST. HELEN'S WATER-WORKS.

PLATE XI.

(Cylinders 28 inches and 52 inches in diameter, stroke 6½ feet.)

In 1873, Mr. Henry Davey erected his first compound differential direct-acting pumping steam engine, at the East Hetton Colliery, Durham. The cylinders were 34 inches and 64 inches jn diameter, having areas in the ratio of 1 to 3.54, with a common stroke of 7 feet. The engine worked a pair of 24-inch bucket-pumps to a depth of 300 feet. This engine appears to have been the first compound double-acting non-rotative pumping engine. It was fitted with Mr. Davey's differential gear. The compound differential pumping engine has since been variously employed for mining, water-supply, and other purposes.

The St. Helen's pumping engine is illustrated by Plate XI. It is employed to lift water from a well 200 feet deep, and to force it to an additional height of 135 feet through 6¼ miles of mains. For this purpose it works two sets of pumps: the lifting-pumps in the well, and the forcing-pumps. The engine is founded on two hollow wrought-iron plate girders, 24 inches high, laid across the well-head, which is 14 feet across at the top. The first and second cylinders are vertical, side by side, 6 feet 9 inches apart between their centre-lines, supported on eight columns. They are 28 inches and 52 inches in diameter, having areas in the ratio of 1 to 3.45, with a common stroke of 6½ feet. They are steam-jacketed about the walls and the top covers. The cylinders are of 1½-inch metal, and the jackets of 1¼-inch metal. The jackets are covered with non-conducting material and mahogany lagging. The steam is supplied by a 5-inch pipe, of ¾-inch metal, and is distributed by means of three double-beat valves at each end of the cylinders, fig. 3. The cut-off valve for the first cylinder is 5½ inches in diameter; the intermediate valve, 10 inches in diameter,

FIG. 2.—SIDE ELEVATION.
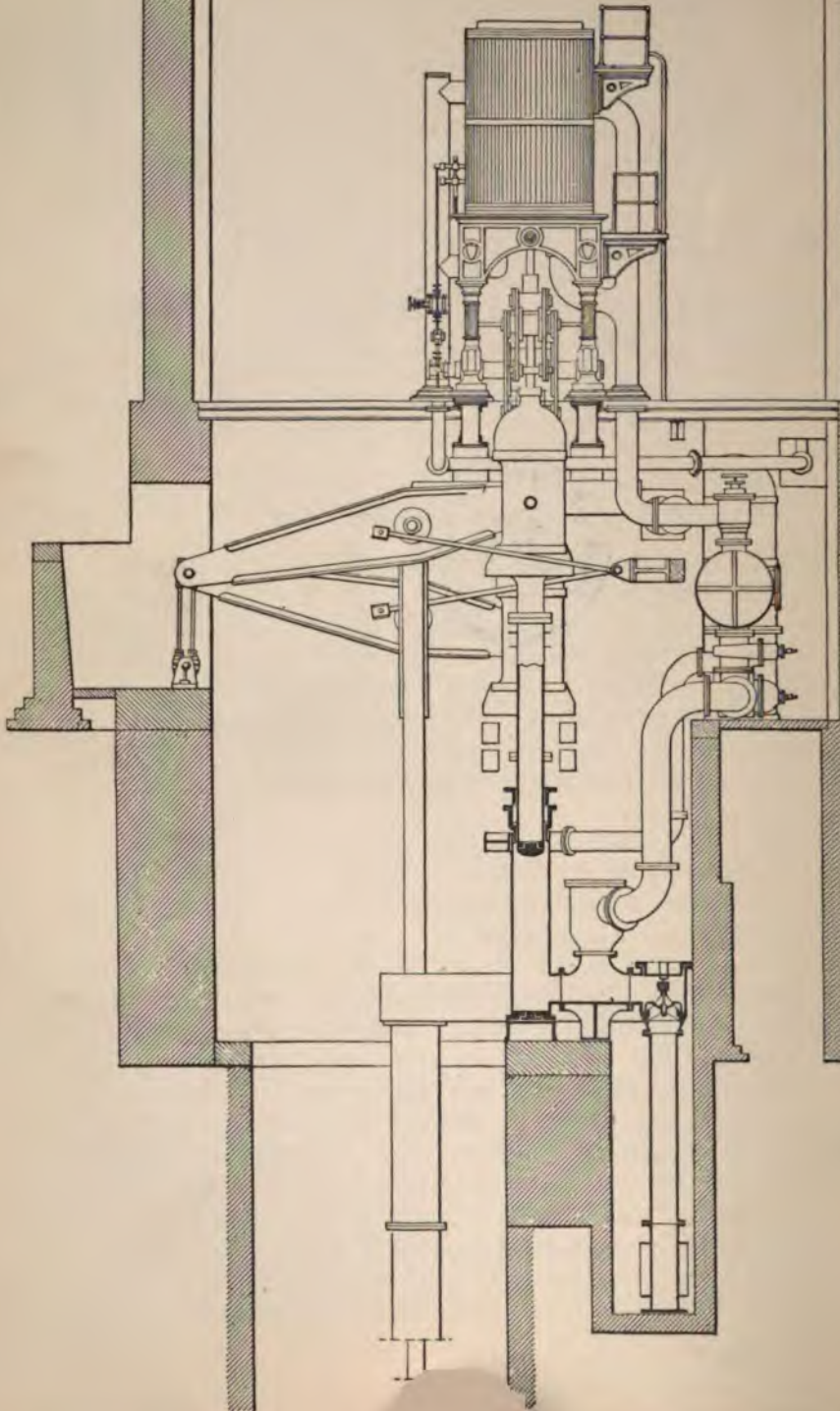
opens for steam exhausted from the first to the second cylinder, and cuts off at about 90 per cent of the stroke; and the third valve, 11 inches in diameter, opens from the second cylinder through an 11-inch pipe, of ⅝-inch metal, to the condenser.

The entablature, of cast iron, supported on eight cast-iron columns, is planed over the whole of the top surface, and the columns stand on planed seatings on the supporting girders.

The plunger or force pumps are each 16 inches in diameter, with a stroke of 6 feet, being connected to and worked directly from the crossheads of the steam-cylinders. They are provided with double-beat valves and seats. The water as delivered from the plunger-pumps is, on its way to the main, passed through a surface-condenser provided with 228 1-inch gun-metal tubes, 6 feet long, having 358 square feet of surface. The connections for water and steam to the condenser may be shut off, the engine then being non-condensing. An air-vessel, having a capacity twelve times that of the pumps, is placed on the main beyond the condenser.

The well-pumps, fig. 646, are open-topped bucket-pumps, 20 inches in diameter, with a common stroke of 4 feet. They are placed out of line vertically with the steam cylinders—about 5 feet to one side, and thus the well-pump rods may be drawn in a direct line by means of the travelling crab overhead, without interference with any part of the engine. The bucket-valves and foot-valves are double-beat. The rods of the well-pumps are of pitch-pine, 9 inches square, joined with strapping plates; and easily disconnected from the engine when required for drawing the buckets, which must be changed through the tops of the pumps, since, when the engine is at rest, the water rises to nearly the level of the top of the well.

The steam-pistons are on Goodfellow's system, fig. 647, in which there are two packing-rings of cast iron side by side, sprung outwards by the pressure of an inner ring of cast iron. The faces in contact are sloped or bevelled, so that, by the action of the inner ring the outer rings are pressed laterally as well as radially, and so make close contact with the sides of the recess in the piston. The pistons are 10 inches thick, of cast iron, of ¾-inch metal for the most part. The packing-rings are together 3 inches wide at the face. The body of the piston is one piece, and the junk-ring is bolted to it.

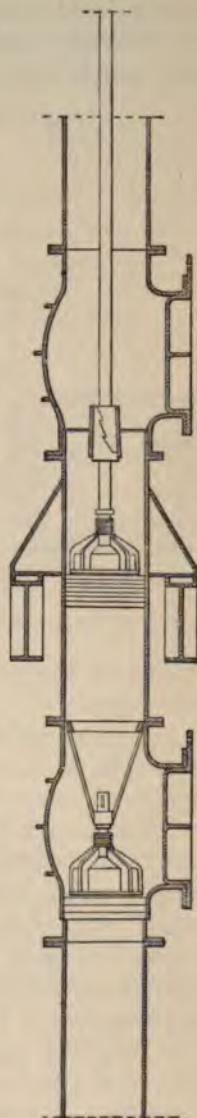The piston-rods are of steel, 5 inches in diameter. They are let into

Fig. 646. — Hathorn, Davey, & Co.'s Compound Vertical Pumping Engine. Section of Well-pump. Scale 1/48th.

and through the pistons with a taper, by which they are reduced to 4 inches in diameter at the upper ends. They are each fastened by a nut 4 inches thick, secured with a through cross-pin; and each rod is cottered into a double-ended crosshead, into the lower end of which the pump-rod is cottered. The piston-rods are connected by means of a characteristic and simple system of three wrought-iron beams or levers, the invention of
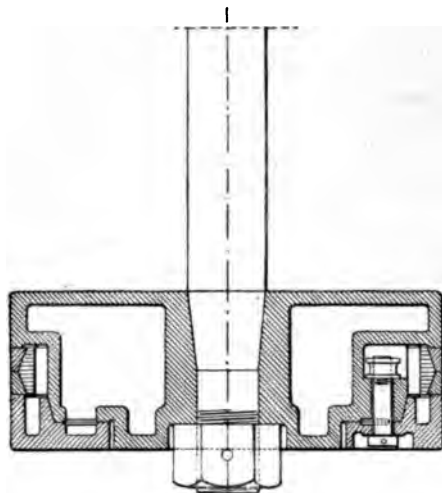

Fig. 647.—St. Helen's Water-works. Piston. 1/12th.

Mr. Davey:—one central lever or vibrating beam of equal arms, 11 feet 9 inches long, between the end centres; and two secondary lateral beams, each 6 feet 4 inches long, centred on the ends of the central beam. The piston-rods respectively are connected to one end of the secondary levers; the other ends of the levers are connected each to a rocking link anchored to a fixed pin; and thus a double parallel motion is constructed, by which the piston-rods and pump-rods are maintained in parallel vertical lines. Besides acting as a parallel motion, the system secures the alternate synchronous reciprocating movements of the pistons, reversely to each other, with regular expansion of the steam.

Each vibrating beam is composed of two 1¾-inch plates framed 2 feet apart in the central beam and 12 inches in the lateral beams. The gudgeons are of steel.

The motions for working the well-pumps are derived from the crossheads of the engine by means of two wrought-iron beams, placed at right angles to the engine beams, 15 feet long. The inner ends of the beams are directly connected to the crossheads, one to each, and the outer ends to rocking links; and a parallel motion is formed by the connection of a pair of radius rods to each beam. The gudgeon to which the pump-rod is connected is fixed in each beam at a point distant about two-thirds of the length of the beam from the rocking-link end; thereby developing a stroke of 4 feet, or two-thirds of the stroke of the pistons.

Steam is supplied by two Lancashire boilers, each 28 feet long, 7 feet in diameter, with two furnace-tubes 2¾ feet in diameter. One boiler suffices to supply the steam required for working the engine; the other is in reserve. The working pressure is from 50 lbs. to 60 lbs. per square inch.

The normal speed of the vertical pumping engine is at the rate of 12 double strokes per minute; but it is capable of making 16 double strokes per minute. The corresponding average speeds of the pistons are 144 feet and 192 feet per minute. The delivery of the pump is said to be over

97 per cent of its net capacity; making about 3 per cent of slip, a liberal allowance when the engine pauses at the end of the stroke. In some instances 98½ per cent delivery has been obtained from similar engines. The water lifted per stroke by the St. Helen's engines is 106 gallons.

The weight of the engine and pumps complete, excluding that of the boilers, is 180 tons.

DAVEY'S DIFFERENTIAL VALVE GEAR FOR DIRECT-ACTING PUMPING ENGINES.

The differential valve gear was designed by Mr. Davey for safety in working, and immunity from stoppages. The steam is supplied to the engine in proportion to the resistance, and in case of a sudden total loss of load the steam is reversed to catch and stop the piston. For this object a cataract, fig. 648, consisting of a steam cylinder controlled by a water cylinder on one spindle or piston-rod, is set to make uniformly the same number of strokes per minute as the engine is designed for, to work synchronously with the engine when at its normal speed. The piston-rod of the cataract is connected by means of a lever to a short arm on the main-lever shaft; and the cataract and the arm reciprocate in unison so long as the engine works at its normal speed. But being pinned to the opposite ends of the lever, they reciprocate reversely, whilst the centre or fulcrum of the lever is stationary. But if the resistance be suddenly diminished or
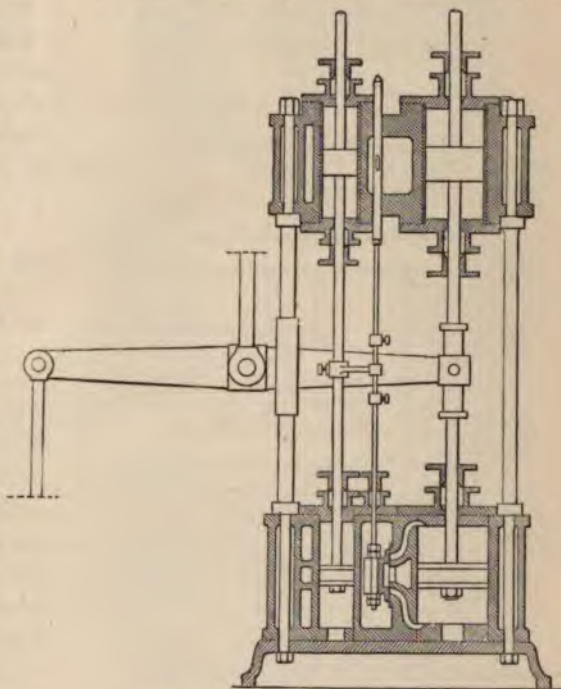

Fig. 648.—Davey's Differential Gear.

altogether cease, the engine starting off at accelerated speed would overrun the regularly-moving cataract, the spindle of which would become the real fulcrum of the lever; and the middle point of the lever, stationary before, would be shifted, and the rod in connection with it would close the valves and so shut off the steam from the working cylinders. In extreme cases, as for instance the bursting of a main or the breaking of a pump-rod, steam would be admitted on the other face of the piston to arrest its motion. At St. Helen's Water-works, by the instrumentality of

the differential gear, the bursting of the main took place without incurring any injury to the engine. Pump-rods have been ruptured at the works in the Mersey Tunnel, and elsewhere, with like results.

A secondary steam water-cataract, known as the pausing cataract, is placed alongside the differential cataract, fig. 648, by the reciprocating movements of which the movements of the steam slide-valve of this cataract are effected. Thus the number of strokes per minute are exactly regulated, whilst the speed of each stroke in itself remains unaltered—a principle of working which has always been recognized in the practice of Cornish pumping engines.
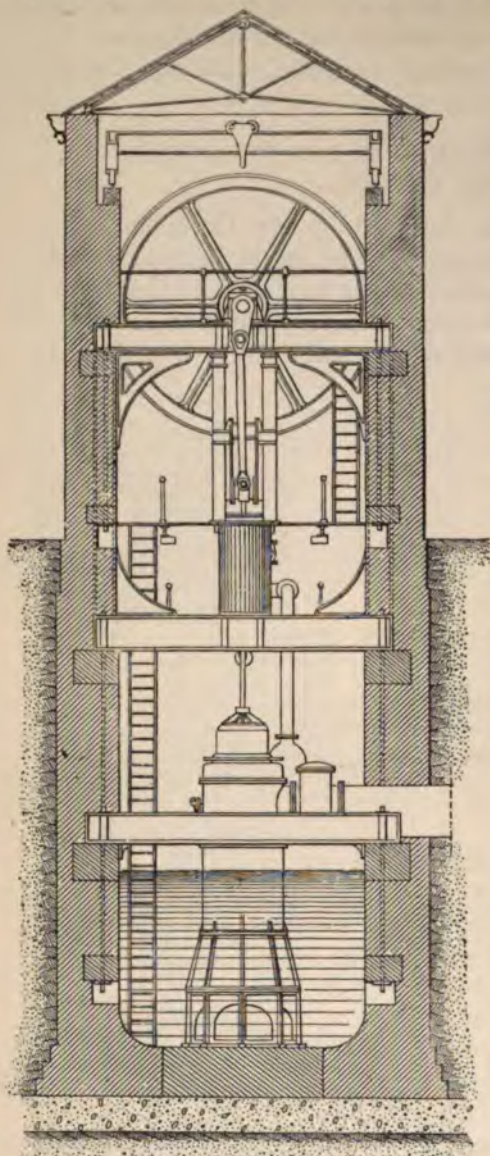

Fig. 649.—J. Simpson & Co.: Vertical Direct-acting Pumping Steam Engine, at Molesey Station, Chelsea Water-works. Scale 1/128th.

CHAPTER XXX.
VERTICAL DIRECT-ACTING CONDENSING PUMPING STEAM ENGINES.

CONSTRUCTED BY
MESSRS. JAMES SIMPSON & CO. FOR THE MOLESEY STATION, CHELSEA WATER-WORKS.

(Cylinder 28 inches in diameter, 4-feet stroke.)

Two compact vertical direct-acting pumping engines, fig. 649, were erected for working low-lift pumps at the Chelsea Water-works' intake at Molesey, the water being lifted into settling reservoirs. The cylinders are 28 inches in diameter, with a stroke of 4 feet; fitted with slide and expansion valves. A bucket-and-plunger pump, 4½ feet in diameter, is worked off a prolongation of each piston-rod. The fly-wheel shaft is overhead, and takes its bearings at the crank end on a transverse cast-iron beam built into the walls, and at the other end on a pedestal in the wall. The framing consists of massive cast-iron box-girders, strongly stayed together. The engines occupy a minimum of floor space.

CHAPTER XXXI.—VERTICAL COMPOUND DIRECT-ACTING ROTATIVE PUMPING STEAM ENGINE.

CONSTRUCTED BY MESSRS. R. MORELAND & SON, LONDON, FOR THE EASTBOURNE WATER-WORKS.

PLATE XII.

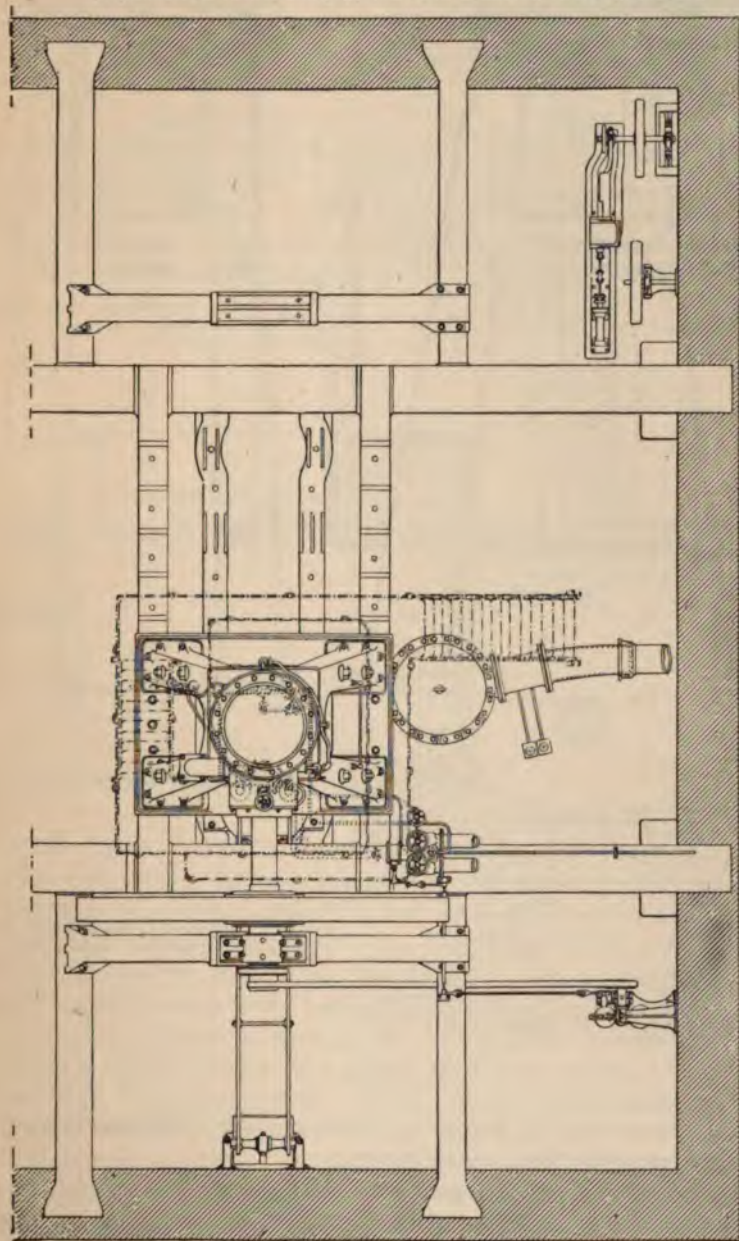(Cylinders 20 inches and 38¼ inches in diameter, stroke 40 inches.)

Fig. 650.—Moreland's Vertical Pumping Steam Engine.   Plan.   Scale 1/96th.

The cylinders of this pumping engine, Plate XII. and figs. 653, are vertical tandem,—the second cylinder being above the first cylinder. The pump is of the bucket-and-plunger type (originally introduced by the late Mr. David Thomson), fixed in the well, below the cylinders, and con-
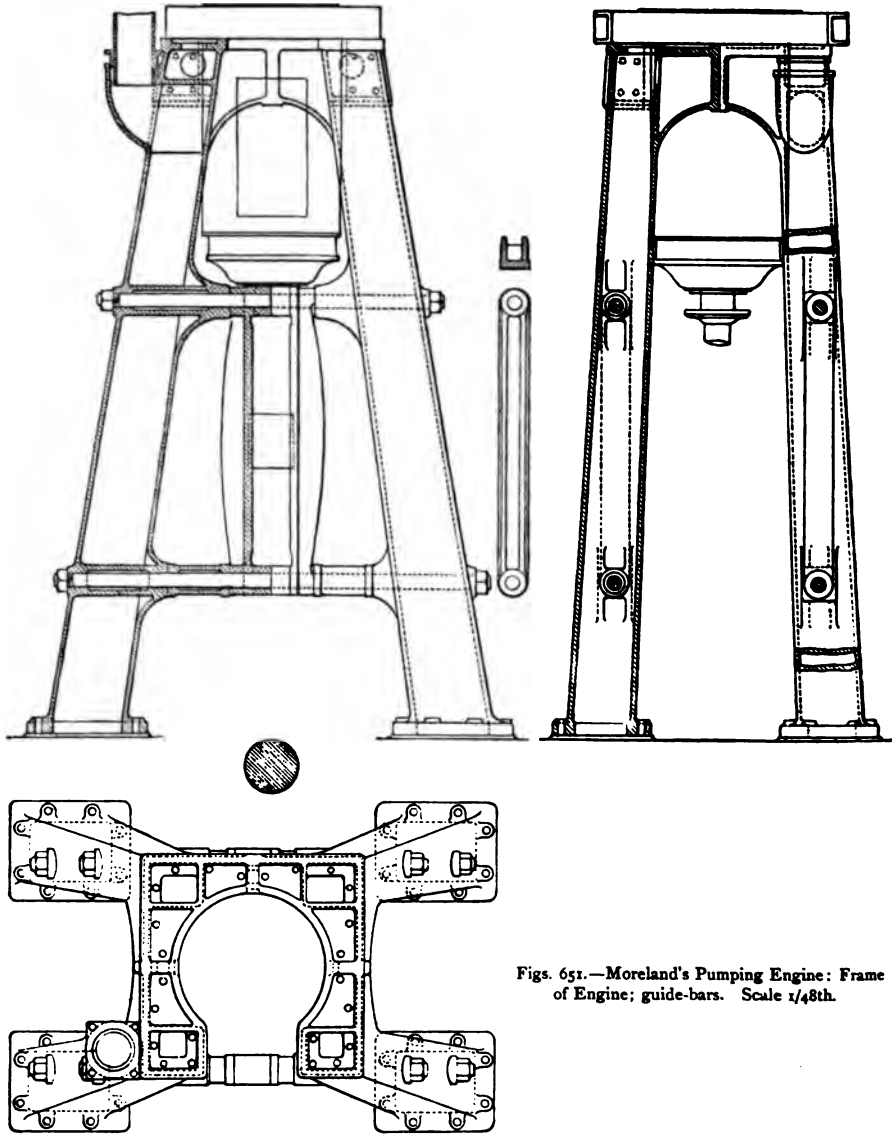
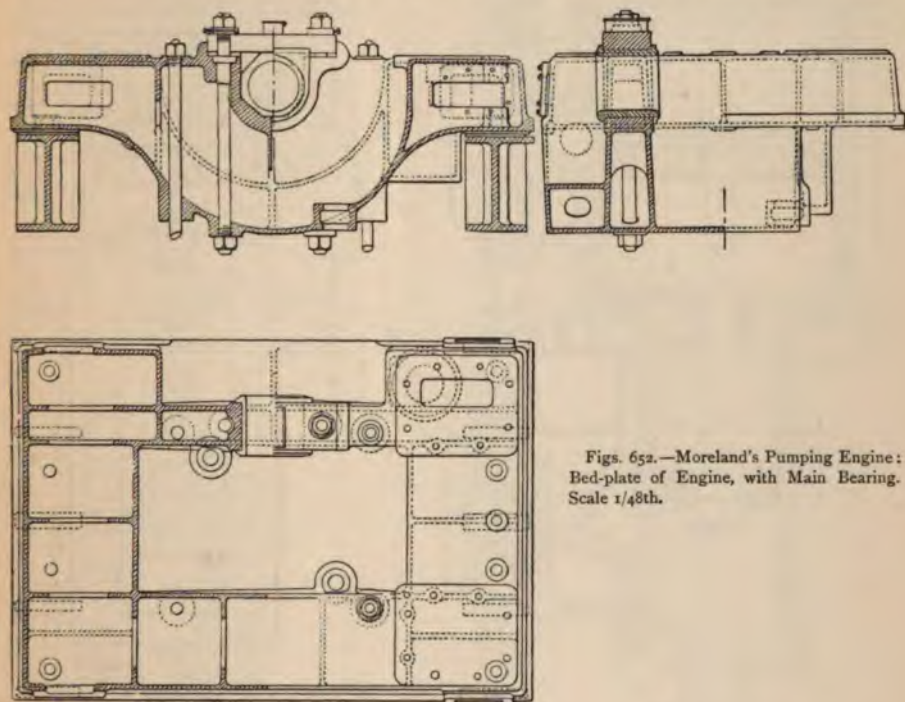Figs. 651.—Moreland's Pumping Engine: Frame of Engine; guide-bars. Scale 1/48th.

nected to the crosshead by two rods. Intermediately, the crank-shaft and fly-wheel are turned by the connecting-rod.

The frame of the engine proper, figs. 651, consists of four corner members or standards, arranged pyramidally, bolted together by brackets at the upper ends, and to the bed-plate, figs. 652, in which the main-shaft

bearing is formed. They support the cylinders on their upper ends. The bed-plate of the engine as well as the outer bearing for the fly-wheel shaft, are supported on longitudinal and transverse beams built into the walls of the engine-house, and these are also carried by columns which are based on transverse beams over the mouth of the well.

The four pyramidal members supporting the cylinders stand 14 feet 4 inches high. They are rectangular in section, averaging 17½ inches by 15 inches, of 1-inch metal. They are bolted to the bed-plate with eight


Figs. 652.—Moreland's Pumping Engine: Bed-plate of Engine, with Main Bearing. Scale 1/48th.

1½-inch bolts and nuts. Besides being tied together by the base-plate at the lower end and the cylinders at the upper end, each pair of standards are tied together by two 3½-inch bolts and nuts, which also pass through and bind the ends of the guide-bars. The lower end of the pyramidal frame is 21 feet above the floor-line; the height of its upper end is 35 feet 4 inches above the floor-line; and the total height of the engine to the top of the second cylinder is 40 feet 11 inches. The bed-plate is of 1-inch metal, and is bolted down to the girders with eight 2½-inch bolts and nuts.

The steam-cylinders, figs. 653, are thoroughly steam-jacketed, and they are directly bolted together. The first cylinder is 20 inches in diameter, with a stroke of 40 inches. It is of 1⅜-inch metal. The case is strictly a liner, cast separately, forced into the jacket by hydraulic pressure. The jacket is of 1¼-inch metal. It is cast in one with a platform at the upper end, 4½ feet square, hollow, 8 inches deep, by which the cylinders take

their bearing on and are bolted to the framing. It has a central opening, forming part of the jacket, into which the partition separating the interiors of the cylinders is fitted and bolted with twelve 1⅛-inch brass stud-bolts and nuts at about 7½ inches of pitch.

The second cylinder is 38¼ inches in diameter, the area of which is to
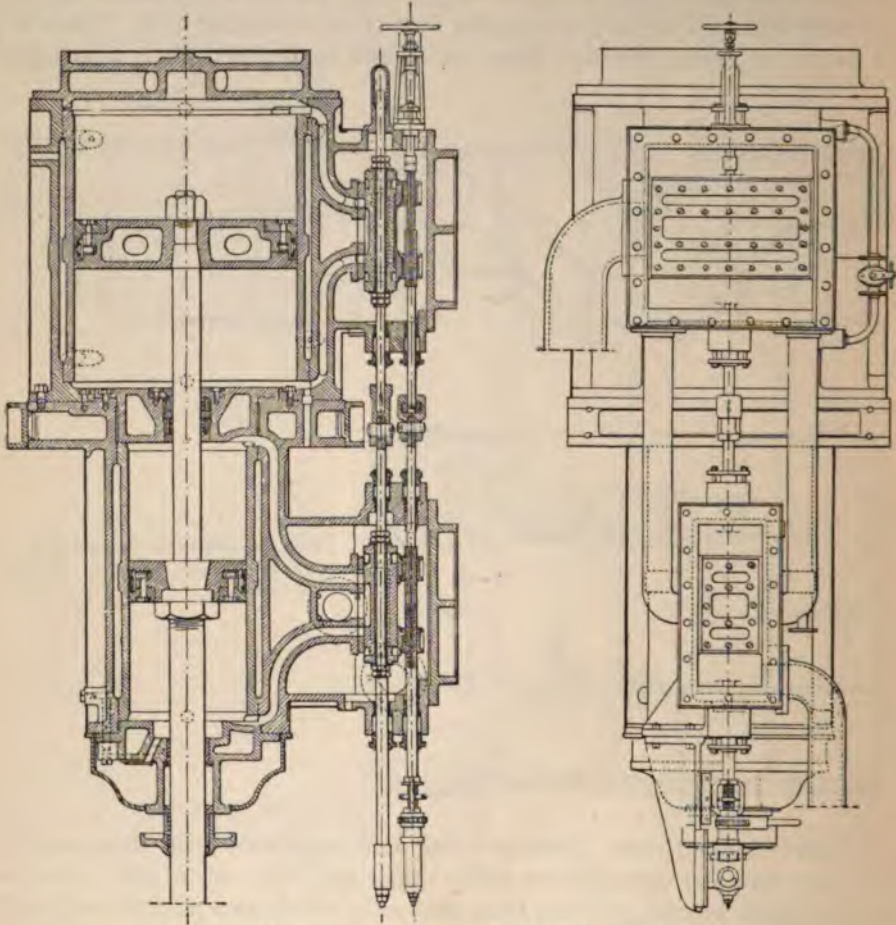
Figs. 653.—Moreland's Pumping Engine: Steam-cylinders.   Scale 1/32d.

that of the first cylinder as 3.66 to 1.   The barrel of the cylinder is cast as a liner, of 1½-inch metal, forced into the jacket.

The second jacket, which is of 1⅜-inch metal, is bolted down to the square platform with sixteen 1¼-inch wrought-iron bolts and nuts exteriorly, at about 9½ inches of pitch; and an inner circle of twelve brass stud-bolts and nuts interiorly, at about 9 inches of pitch.   The jackets are bolted together with sixteen 1⅜-inch stud-bolts.

The cylinder-covers and the middle partition are hollow, and receive steam for jacketing.   The supplies of steam for these jackets are taken

VERTICAL COMPOUND DIRECT-ACTING R
PUMPING STEAM ENGINE,

CONSTRUCTED BY

MESSRS. R. MORELAND AND SON, LONDON, FOR TH

EASTBOURNE WATERWORKS.

Diameter of 1st Cylinder, 20 in.
  ,,   2nd   ,,   38¼ in.
Length of Stroke, 40 in.
Diameter of Air-Pump, 17 in.
Diameter of Pump-barrel, 20 in.
Diameter of Plunger, 15 in.
Speed, 23½ Double Strokes per minute.
Indicator Horse-power, 91 H.P.
Duty, 86 per cent.

FIG. 1.—FRONT ELEVATION.

SCALE ¹⁄₁₆ INCH = 1 FOOT, OR 1-64TH.

PLATE XII.

Fig. 2.—SIDE ELEVATION.
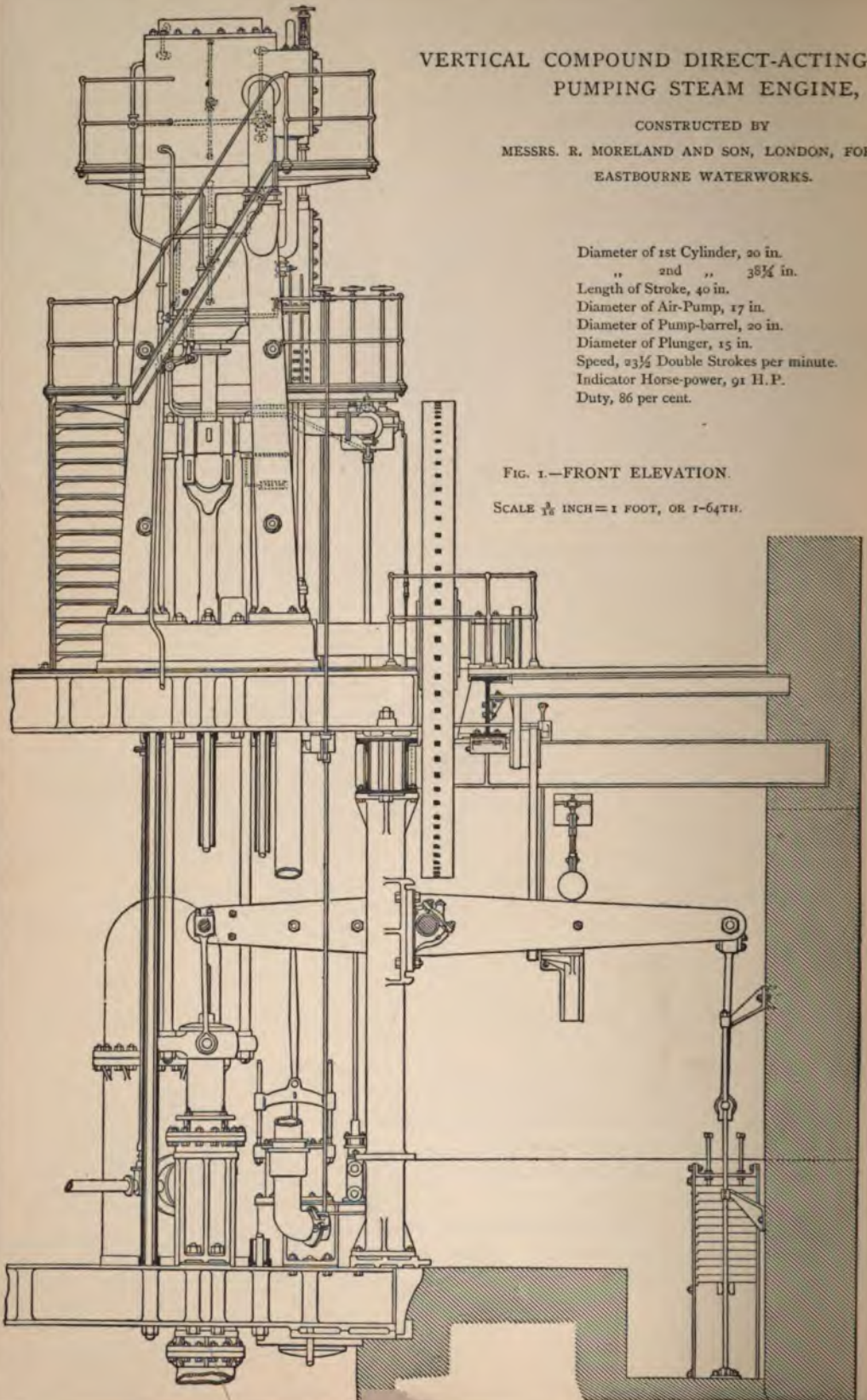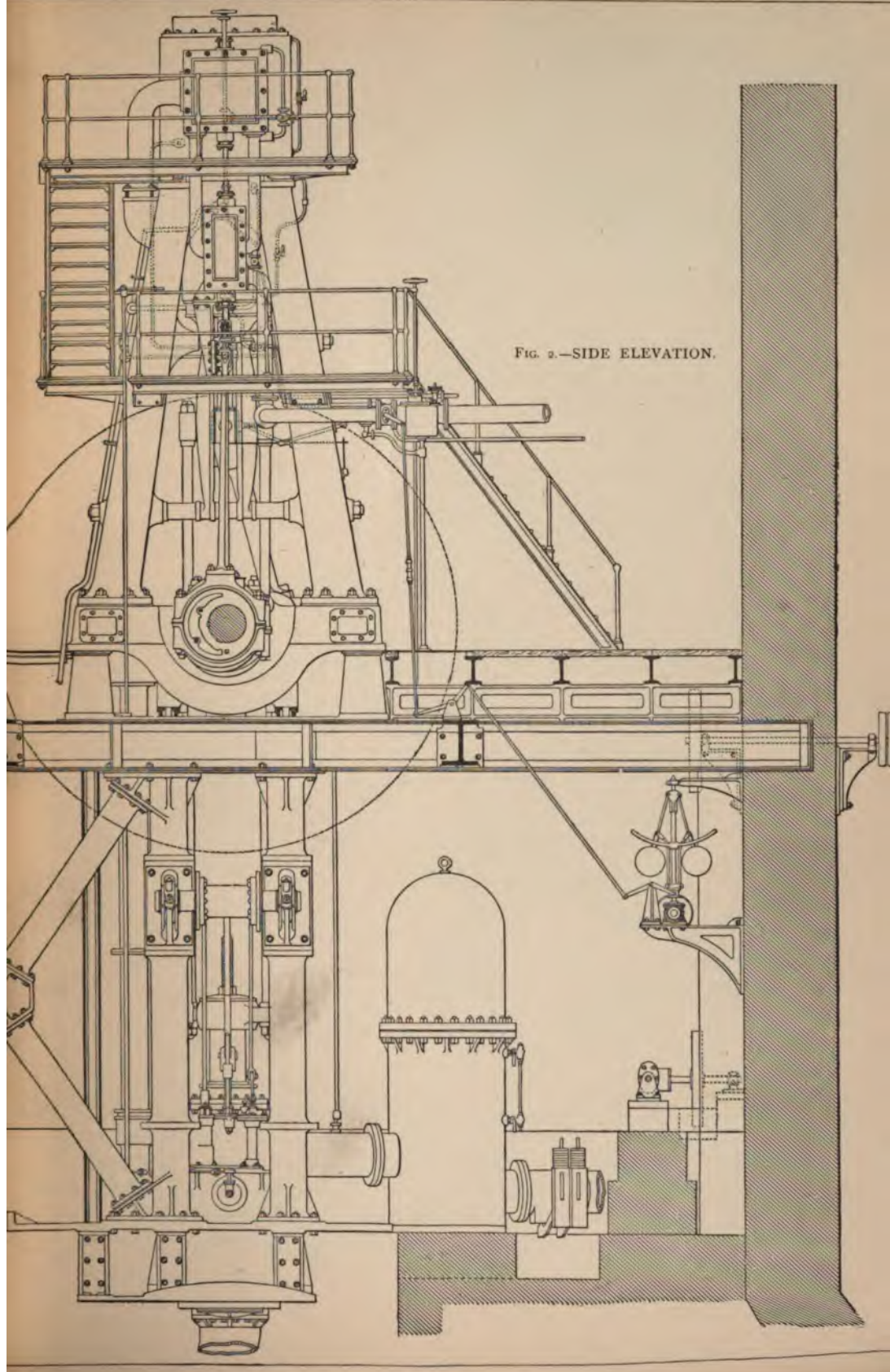
from the side jackets, by means of short bent tubes, as indicated by the annexed sketch, fig. 653a. The first cover is fastened with ten 1¼-inch stud-bolts; and the second with sixteen 1⅜-inch stud-bolts. The covers are packed in the usual manner; the partition is made tight with me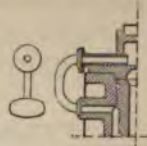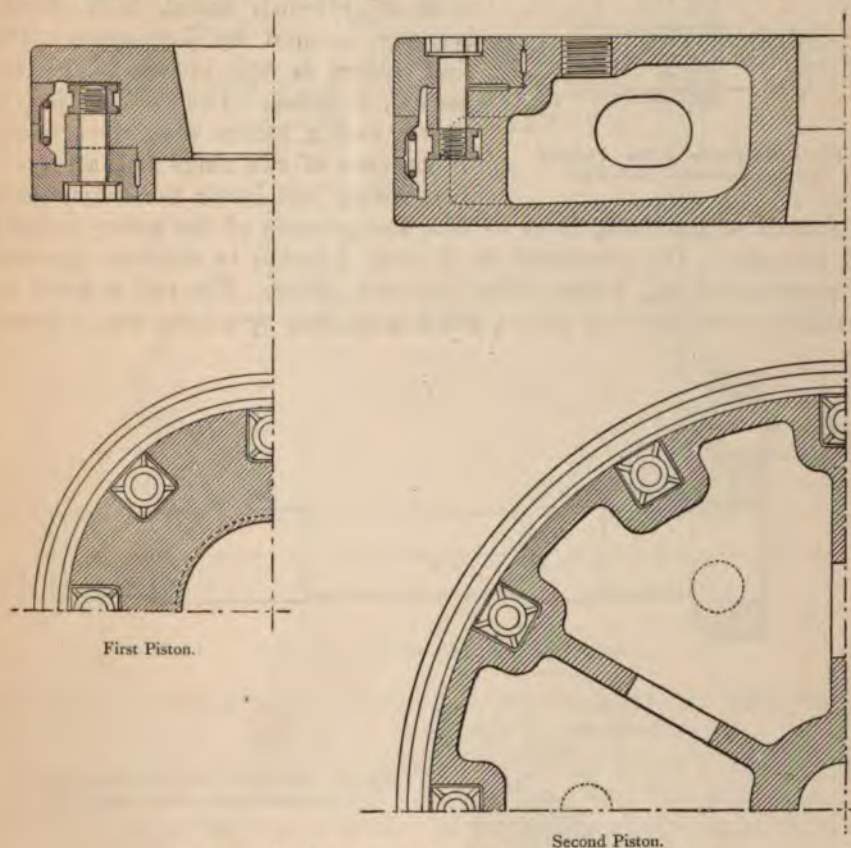tal packing, which consists of two cast-iron rings bored slightly smaller than the piston-rod, split, and fitted with springs behind the rings.

Fig. 653a.

The valve-faces are cast of special metal, and pinned on the cylinders. The steam-ports of the first cylinder are 1¾ inches by 6½ inches; the

First Piston.

Second Piston.

Figs. 654.—Moreland's Pumping Engine: Steam Pistons. Scale 1/8th.

exhaust-port is 4 inches long: their areas being respectively 1/28th and 1/10th of the area of the cylinder. The steam-ports of the second cylinder are 1¾ inches by 23 inches; the exhaust-ports are 4 inches long: their areas being 1/28.3 part and 1/12.3 part of the cylinder area.

Steam is brought to the first cylinder by a 5-inch cast-iron pipe, of ¾-inch metal; and it is conducted from the first to the second cylinder by two 4½-inch copper pipes, fully 3/16 inch thick, one from each side of the

exhaust-port to the second valve-chest. It is exhausted from the second cylinder through a 9-inch cast-iron pipe of ⅞-inch metal, into one of the pyramidal members of the framing, from the lower end of which it passes to the condenser.

The guide-bars, figs. 651, are of cast iron, in pairs, 7¼ inches across the faces, 9 inches apart, fastened to the framing, as already described.

The pistons, figs. 654, are of cast iron, of 1⅛-inch metal, with Prior's packing, secured by junk-rings. The first piston is 6½ inches thick; the second, 8 inches. The packing is 3¾ inches and 4 inches wide respectively. It consists of two rings and a serpentine spring laid inside the rings, which

Figs. 655.—Moreland & Son. Pumping Engine: Crosshead. Scale 1/32d.

are formed with sloping faces to take the pressure of the spring radially and laterally. The piston-rod is of steel, 5 inches in diameter between the pistons, and 6¼ inches below the first piston. The rod is made up conically to take the first piston, which is secured by a brass nut 5 inches
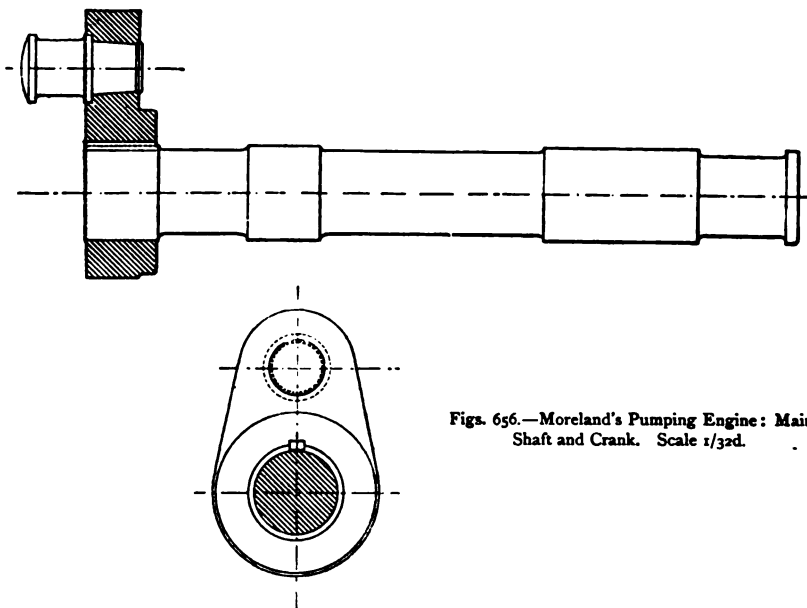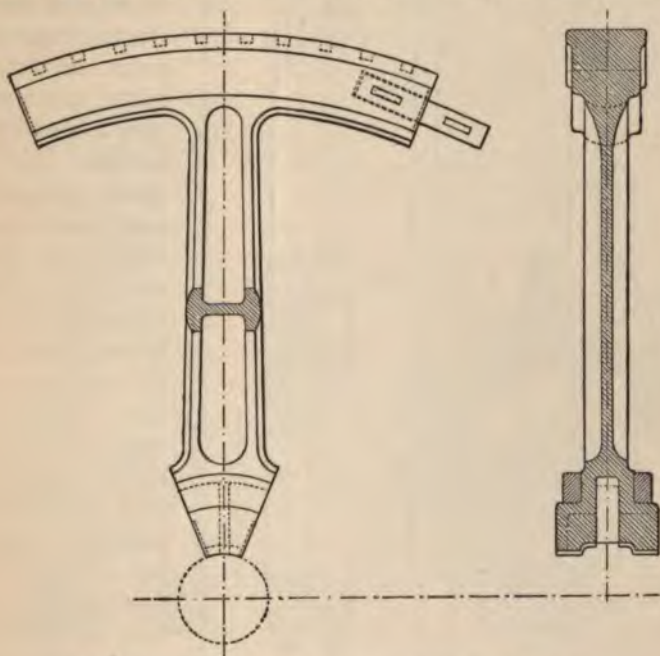
Figs. 656.—Moreland's Pumping Engine: Main Shaft and Crank. Scale 1/32d.

thick. The end of the rod is tapered upwards to take the second piston, which is secured to it with a brass nut 4 inches thick. The first piston can be taken out downwards, and the second piston upwards.

The crosshead, figs. 655, is of Bessemer steel, 13 inches deep at the centre,

cottered on the piston-rod. The slides are 14 inches deep. The two journals are 9 inches in diameter, each 5½ inches long. Two horns or studs are forged solid on the crosshead to take the two rods placed diagonally, to clear the crank and shaft by which the crosshead is connected to the plunger of the pump.

The connecting-rod is of scrap iron, 6 feet 8 inches long, or four times the length of the crank. It is forked to take the crosshead, the two bearings being 9 inches in diameter, 5½ inches wide, made with a butt and strap, gibbed and cottered. The crank-end is of the cap-and-bolts construction,

Figs. 657.—Moreland's Pumping Engine: Fly-wheel. Scale 1/32d.

with a bearing 8½ inches in diameter, 8 inches long, and two 3-inch bolts and nuts. The body is cylindrical, 6⅝ inches in diameter.

The crank-shaft, figs. 656, is of Bessemer steel, 13½ inches in diameter in the body and at the journals, which are 15 inches long. The shaft is made up to 14½ inches at the boss to receive the fly-wheel, and 15½ inches for the crank and the eccentrics. The crank is of forged scrap iron, and is bored to 15½ inches in diameter, and shrunk on and keyed to the shaft. The crank-pin is of Bessemer steel, having an 8½-inch journal, 8 inches long. The eye of the crank is shrunk on the pin, the end of which is riveted over the eye. The pin is also keyed into the eye. The fly-wheel, figs. 657, is 15 feet 7 inches in diameter. It has eight arms. The rim is made of eight segments, cast in one with an arm and a segment of the centre. Their joining surfaces are planed and connected by wrought-iron dowels and keys. The centre is bored out, and is turned to receive two binding-hoops of

wrought iron, 5 inches by 3 inches thick, shrunk on when the wheel is in position.

Each cylinder is constructed with a valve-face of hard cast iron, 1 inch thick; and is fitted with a main slide-valve and a variable expansion-valve working on the back of the main-valve, figs. 653, page 286. The main-valves are worked in line by one eccentric, and the expansion-valve by another eccentric. The eccentrics, figs. 658, are of cast iron, each in one piece, 28 inches in diameter, 4½ inches wide, with a throw of 6 inches; fastened together with three 1¼-inch countersunk pins; bored and keyed on the shaft, which is 15½ inches in diameter, with two steel keys. The straps are of cast iron with brass liners, in halves, joined with two long 1¾-inch bolts and double-nuts. The eccentric-rods are fastened each with a palm to the straps, and two stud-bolts and nuts; and are pinned to the valve-spindles with steel pins. The main valves have 1½ inches of lap, ¼ inch of lead, 6 inches of travel, cutting off at three-fourths of the stroke. The spindles are of Bessemer steel, 2½ inches in diameter below the first valve, and 2 inches above it. Each expansion-valve is in two parts, adjustable, on the Meyer system, by means of a right-and-left-handed screw of ½-inch pitch. The spindle is 2⅛ inches and 1⅝ inches in diameter. The expansion-valves are capable of being adjusted independently. The expansion index on the second cylinder is illustrated by fig. 659. It is shown in its place in figs. 653.

The condenser, fig. 660, is at the floor line, supported by the pump-girders. It is 3½ feet in diameter, 4½ feet high, of ¾-inch cast iron. The air-pump, inside the condenser, is of cast iron, 1 inch thick. It is single-

Figs. 658.—Moreland's Pumping Engine: Eccentrics for Main Slide and Expansion-valve. Scale 1/20th.

acting, 17 inches in diameter, worked off the balance-lever, one end of which is linked to the crosshead of the plunger, with a stroke of 2 feet. A non-return valve is placed on the discharge-pipe from the hot-well. The feed-pump is carried on the top of the condenser; it is 3½ inches in diameter, single-acting, with a stroke of 13 inches, worked off the balance-lever. The air-charging pump for supplying the air-vessel is also fixed on the condenser; single-acting, with a 3-inch plunger, and worked off the lever with a 13-inch stroke. The bucket of this pump is
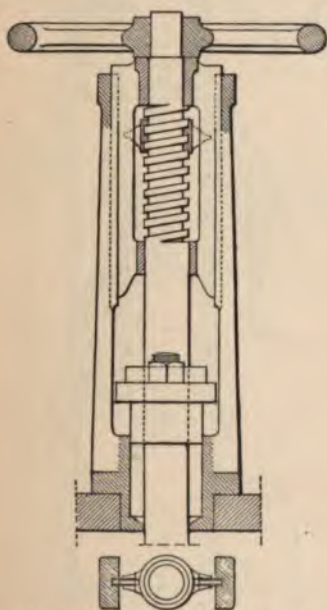
Fig. 659.—Moreland's Pumping Engine: Expansion-index on Second Cylinder. Scale 1/6th.
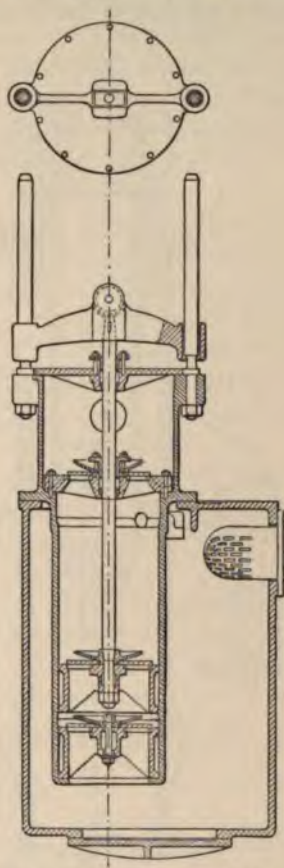
Fig. 660.—Moreland's Pumping Engine: Condenser and Air-pump. Scale 1/32d.

packed with leather, with 1-inch valves, and can be stopped forcing by freeing the suction-valve, when air-supply is not required.

The two rods connecting the crossheads of the engine and pump are of Bessemer steel, 4 inches in diameter. The crosshead of the pump-plunger, figs. 661, is a forging of Bessemer steel, 11 inches deep at the centre. It is bored out larger than the plunger, and is lined with a bush, in halves, through which the downward pressure is transmitted to the plunger. By this disposition the plunger and rods can be passed through the crosshead, and freed for inspection of the suction-valve when required. The pump, of the bucket-and-plunger type, has a 20-inch working barrel, with a 15-inch plunger. The bucket is of cast iron, with gun-metal valves and beats. The pump is carried by the well-girders by means of brackets on the

uppermost pipe. The weight of the pump, steam-pistons, and other re-
ciprocating masses, is balanced by an adjusted counterweight at the wall
of the engine-house, by the medium of a lever which is linked to the
plunger crosshead. The arms of the lever are respectively 10 feet and
7½ feet long, giving the counterweight a leverage of 4 to 3. The lever is
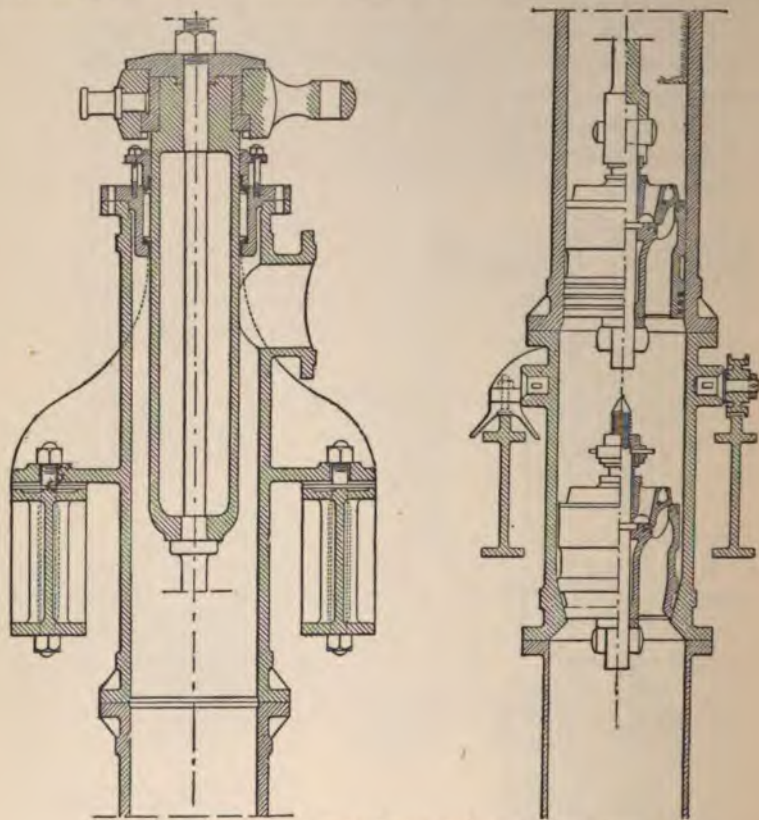
Figs. 661.—Moreland's Pumping Engine: Main Pump. Scale 1/32d.

of two 1½-inch wrought-iron plates, 24 inches deep at the centre, 23 inches
apart, stayed together; vibrating on a gudgeon having 8-inch journals.

The air-vessel is connected to the pump by a 14-inch cast-iron pipe,
1¼ inch thick. It is of cast iron, 2⅜ inches thick; 3½ feet in diameter,
with 12 feet total height. The top is fastened to the body with twenty-six
1¾-inch bolts and nuts. The volume of air in it when the water is at the
working level is 75 cubic feet, or about twenty-two times the volume dis-
charged from the pump for one stroke. A stop back-valve, working in a
brass seat, is fitted on the inlet from the pump. Two 5-inch lever safety-
valves, capable of discharging the whole of the water thrown by the pump,
with a slight increase of head, are fitted on the discharge-pipe beyond the
air-vessel; also a 3-inch easing cock, to relieve the pump of pressure when
starting.

The rising main is 21 inches in diameter, of $1\frac{7}{8}$-inch metal, with $2\frac{3}{8}$-inch flanges. The suction-pipe is $22\frac{3}{4}$ inches in diameter, of 1-inch metal. It is fitted with a wrought-iron rose, 24 inches by 40 inches by 24 inches, on the end; 55 feet below the well-girders.

The bucket and the suction-valve are 20 inches in diameter, exact duplicates, except that the entrance to the suction-valve is contracted conically

to fit the bored seat in the suction-box. The bucket is packed with three manganese-bronze rings, $\frac{3}{4}$ inch by $\frac{5}{8}$ inch in section. The spindles are 4 inches in diameter. The valves are double-beat, of gun-metal, with conical seats, and a maximum lift of $1\frac{1}{2}$ inches. The beats and the slide parts of the spindles are lined with gun-metal. The suction-valve is loaded with lead. The pump-rods through the rising main are of Bessemer steel, scarf-jointed, secured in cast-steel boxes.

The pumping engine just described was tested in February, 1884, on low-service work, for a period of 12 hours.[1] Specimens of the indicator
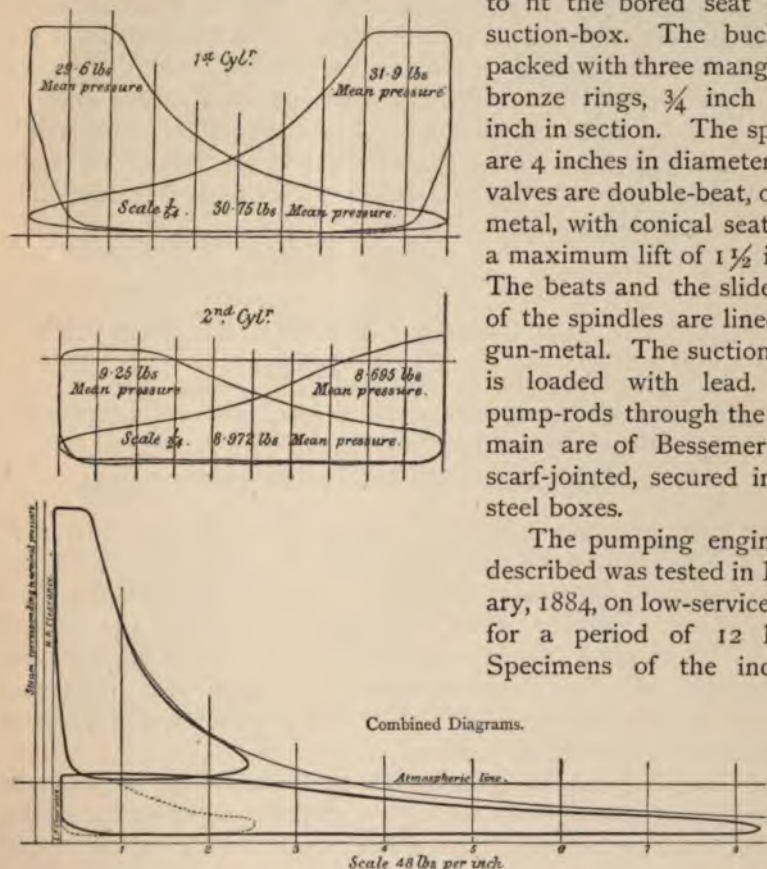
Figs. 662.—Moreland's Pumping Engine: Indicator Diagrams.

diagrams taken are represented by figs. 662; pieced together in the lower figure; from which it appears that steam was cut off at about 20 per cent in the first cylinder, and at about 27 per cent in the second cylinder: showing a nominal working expansion of $\left(\dfrac{100}{20} \times \dfrac{100}{27} = \right)$ 18.5 times. The average pressure in the boiler was 69.15 lbs. per square inch above the atmosphere. The initial pressure in the first cylinder, by the diagrams, was 69 lbs. above the atmosphere, reduced by expansion to 8 lbs. at the end of

[1] The results above given are derived from a published report in *Engineering*, December 5, 1884, page 520, &c.

the stroke. In the second cylinder the initial pressures were 3½ lbs. and 1½ lbs. above the atmosphere; and there was 12½ lbs. of vacuum in the cylinder; and 28.58 inches of mercury, or 14 lbs. per square inch of vacuum in the condenser. The engine made 23.44 double-strokes per minute, or a speed of piston of 156.3 feet per minute. There was developed 90.70 indicator horse-power. The total lift of water was 243.94 feet; the delivery was at the rate of 1054.8 gallons per minute, making 77.97 horse-power of duty, or 86 per cent of the indicator power. The coal consumed per hour was 138.83 pounds, or 6.31 pounds per square foot of fire-grate, or 1.78 pounds per horse-power of water raised, giving a duty of 124.6 millions of foot-pounds per hundredweight of coal. From other observations, it appears that the consumption of steam was at the rate of 18 pounds per pump horse-power, or 15.46 pounds per indicator horse-power, including the steam used in the jackets.

Chapter XXXII.—BEAM COMPOUND PUMPING STEAM ENGINES,

FOR THE LAMBETH WATER-WORKS, BRIXTON HILL, LONDON; CONSTRUCTED BY MESSRS. EASTON & ANDERSON, LONDON AND ERITH.

(Cylinders 22½ inches and 45 inches in diameter, stroke 5½ feet.)

Two beam compound pumping engines, figs. 663 and 664, were constructed according to the specification of Mr. John Taylor, the engineer to the company, and were erected in 1875–76, for pumping 5,000,000 gallons of water per day, when working together, from the reservoirs on Brixton Hill to the Norwood reservoir. The normal head, including friction, is about 230 feet. The engines were proportioned with a margin of safety of 10, for a maximum lift of 280 feet, and they have frequently been worked under a total lift of 320 feet.

The first and second cylinders of each engine are on separate bed-plates with separate beams, working on cranks at right angles on the main shaft, each driving a double-acting pump. The first engine was ordered for raising 2,250,000 gallons of water. The engines stand side by side in the same house, and are of the same design and construction; but the second engine has larger diameters and a longer stroke than the first:—

	1st Engine.	2d Engine.
Diameter of 1st cylinder,	21 inches	22½ inches.
Do.　2d　do.	42　„	45　„
Length of stroke,	5 feet	5½ feet.
Normal speed in turns per minute,	22	22.

Each bed-plate, shown in section, fig. 665, is of cast iron, and is 23¾ feet long, 5 feet 4 inches wide, 15½ inches deep, hollow, consisting of two side longitudinal members connected by two transverse members, and a web to form a seat for the cylinder. The top is planed for receiving the cylinder and

other fixings. The frame is of 1½-inch metal in the top, 1 inch in the sides, principal cross ribs, and bottom. It is ribbed longitudinally and transversely
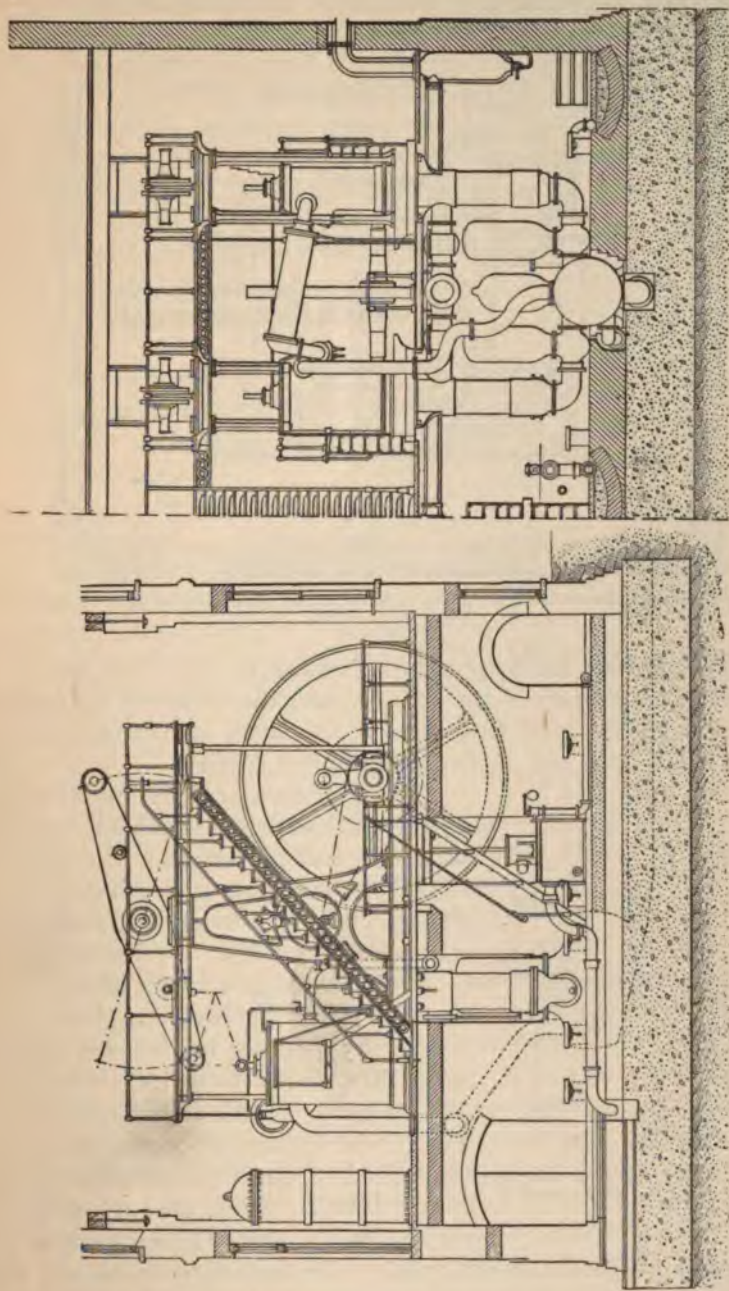
Figs. 663.—Easton & Anderson: Compound Pumping Steam Engine, Brixton Station, Lambeth Water-works. Elevations. Scale 1/128th.

of ¾-inch metal under the cylinder platform. The entablature is supported by two **A** frames, under the beam centre, and two small wrought-iron

columns at each end. The **A** frames have a base 8 feet 2½ inches long on the bed-plate. They are 10 feet 5 inches high to the entablature, for which they give a bearing 2½ feet long. The entablature is 11 inches deep, and is self-contained. The pedestals for the beam centre are 19½
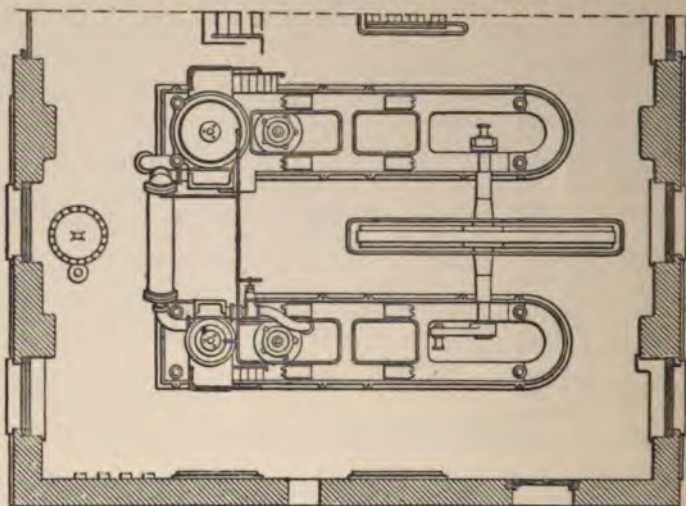
Fig. 664.—Easton & Anderson: Compound Pumping Steam Engine, Brixton Station, Lambeth Water-works. Plan. Scale 1/128th.

inches high; making the height of the centre 12 feet 11½ inches above the bed-plate. The axis of the cylinder and the centre of the main shaft are 15 feet 8 inches apart, horizontally; the beam is 16 feet ¾ inch long between the end centres.
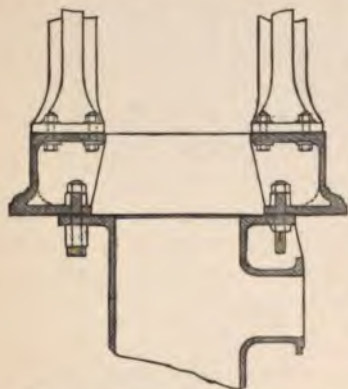
Fig. 665.—Easton & Anderson: Pumping Engine, Brixton: Cross Section of Bed-plate. Scale 1/36th.

The cylinders are steam-jacketed and lagged, and fitted with double expansion-slides, of which those on the first cylinder are adjustable by hand while the engine is at work. The steam exhausted from the first to the second cylinder is reheated and dried by passing through a faggot of fifteen 3-inch tubes, 6 feet 2 inches long, inclosed in a cylinder 15¼ inches in diameter, into which steam direct from the boiler is admitted.

The beam of each engine consists of two wrought-iron plates, 32 inches deep at the centre, riveted together, with intervening blocks of cast iron, by which the several gudgeons are supported; and a lead counterweight to balance the pump, near the outer end. The main-shaft, crank, connecting-rod, valve-gear, and pump-rods are of wrought iron. The connecting-rod and pump-rod are round in section. The fly-wheel, figs. 666, is 15 feet in diameter, 7¾ tons in weight; in two halves, bolted and dowelled together.

The main service pump in each engine is of the double-acting bucket-and-plunger type, having a 22½-inch barrel, and a stroke of 2¾ feet; bolted direct to the under face of the bed-plate, midway between the cylinder and the main centre.   It is worked by a rod off the parallel motion that guides the cylinder crosshead.   The barrel is of hard cast iron, and the pump bucket is packed with two pairs of gun-metal spring rings, ¾ inch wide, in two grooves—one pair in each groove, on the supposition that one ring of each pair keeps the other ring lively, and that so sticking is prevented.   Each pump is fitted with a flat retaining valve on its delivery branch.   The valves in the clacks and the buckets are of the annular ring system, in three concentric rings, falling on gun-metal seats.

The engine-house is of brick, 54 feet long, 35 feet wide inside, 37½ feet high from the basement to the wall-plate.   There are two complete masonry floors; the upper or main floor at the top of the foundation - piers or walls of the engine being 10 feet above the basement.   The foundations for the engines consist of
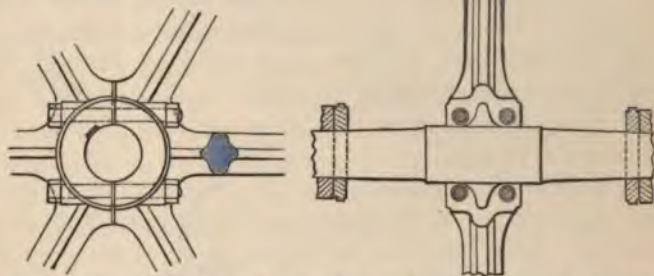
Figs. 666.—Easton & Anderson; Pumping Engine, Brixton: Fly-wheel.   Scale 1/40th.

four parallel piers of brickwork, 6½ feet wide, 10 feet high, crossing the engine-room, with inverts and arches between them, and gaps through them for gangways and to make room for the pumps.   The walls of the engine-house and the piers rest on a continuous bed of concrete 3 feet thick, laid on the London clay.

The water is raised from reservoirs behind the house, the level of the water varying between those of the upper and lower floors of the engine-house.   Each pair of pumps draws water through an 18-inch suction-pipe, and thence through a surface-condenser.   The two suction-pipes to the pumps branch from the top of the condenser; and an air-vessel, having a capacity of 280 gallons, is placed over the condenser.   The discharge-pipes from the two pumps meet in a junction-pipe, and pass thence through a 15-inch pipe to the second air-vessel, 2½ feet in diameter, which, at normal level, has 280 gallons of capacity for air, or three times the discharge of the two pumps together for one revolution.   The water-level in the air-vessel only oscillates about 2½ inches for each revolution.   To prevent air entering the main easily from the air-vessel, in case the pressure should be reduced suddenly, the delivery-pipe from it, 18 inches in diameter, passes

the water vertically downwards to the lower floor level, thence through the wall of the engine-house to join the water in the main outside. The air-vessel is automatically supplied with air.

The surface-condenser, fig. 667, is of cast iron, cylindrical, 7 feet 5 inches long, 3¼ feet in diameter, with a segmental cover on each end. It contains 460 brass tubes, ¾ inch in diameter, 5¾ feet long between brass plates, packed with wood ferules. The water passes over the outsides of the tubes; the steam passes inside. The water in passing through the condensers is raised in temperature about 2¼° F. The area of tube-surface in the condenser is about 2¼ square feet per maximum indicator horse-power. A larger proportion of area in the first engine was found unneces-sary, and several tubes were removed, with advantage.

The air-pump of the engine is 15 inches in diameter, with a stroke of 2 feet 8 inches, the capacity of the up-stroke being about 2 gallons per maximum indicator horse-power. It is placed under and is worked from the second beam, on the side next the crank. The feed-pump is corre-spondingly placed and worked by the first beam.

The condensation-water from the steam-jackets, reheater, and separator, is collected in copper pipes, and conveyed to a central vessel so placed that the suction-water for the feed-pump passes through it and mingles with it on its way to the pump.

At the nominal speed of the engines, 22 turns per minute, 2083 gallons of water should be delivered per minute. The stipulated duty would allow a reduc-tion of 5 per cent off the full working capacity of the pumps. The engine-room is spanned by a travelling crane above the engine, cap-able of raising the heaviest piece.

The two pumping engines are supplied with steam from five double furnace-

Fig. 667.—Easton & Anderson : Pumping Engine, Brixton: Surface-condenser. Scale 1/24th.

tube boilers, 7 feet in diameter, 21 feet 7½ inches long, with 2-feet-9½-inch furnace-tubes; at a working pressure of 60 lbs. per square inch. Two boilers can supply steam to both engines working at full speed; but ordinarily three boilers are worked at the same time.

The total cost of the two pumping engines, with their pumps and five boilers, was £21,905. The engine-house and boiler-house, with the foun-dations and flues, cost about £6000.
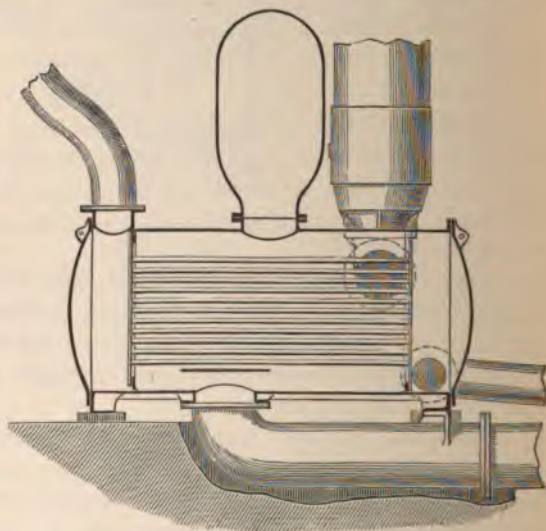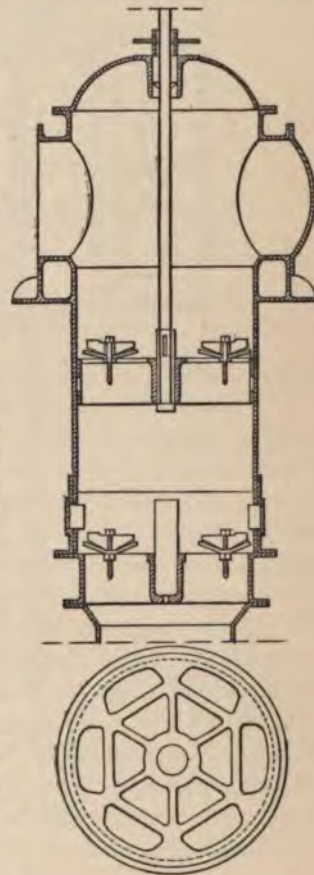
CHAPTER XXXIII.

WOOLF BEAM SEWAGE-PUMPING STEAM ENGINES.

CONSTRUCTED BY MESSRS. EASTON & ANDERSON FOR BUENOS AYRES.

(Cylinders 24 inches in diameter, 46 inches stroke; and 36 inches by 72 inches.)

These engines, figs. 669, constructed in 1883, embody most of the principles shown by the practice of constructors to be most desirable in large pumping engines. They are four engines arranged as two coupled pairs, whilst any one engine can be worked singly. Two pumps are worked by each engine, or eight pumps by four engines, under a gross lift of 50 feet, 13,100 gallons of sewage being raised per minute, whilst the engines make 15 turns per minute,—their normal speed; or 17,500 gallons for a speed of 20 turns per minute,—the maximum speed. The bed-plates and **A** frames are formed throughout in cellular box-sections. The **A** frames are carried up to include the main centre-bearings at the summits, and they are stiffened transversely by distance-pieces, of box-section, bolted between them just below the beams. The spring beams are built at the ends into the walls. The first cylinder of each engine is 24 inches in diameter, with a stroke of 46 inches; the second cylinder is 36 inches by 72 inches: the capacity-ratio being 1 to 3½. The cylinders are steam-jacketed, and the first cylinders are fitted with expansion-valves, so that the engine can be worked at very low speeds. The air-pump and the feed-pump are worked off a small beam or lever beneath the main floor, which is moved by links from a crosshead on the first piston-rod.

One of the service-pumps is driven by the first piston-rod, extended through the bottom of the cylinder: so arranged as to admit of the pump being opened out. The other pump is worked off the main beam, from the crank half. That a single rod may be employed for working this pump, without fouling the lower end of

Figs. 668.—Buenos Ayres Water-works: Service-pump. Scale 1/64th.

the connecting-rod of the engine, the centre of the main shaft has been placed 12 inches further from the centre of the engine than the axis of the second cylinder is placed; and the outer end of the main beam has been turned upwards to enable it to work the main shaft in its new position in a satisfactory manner, without requiring the stroke to be increased.
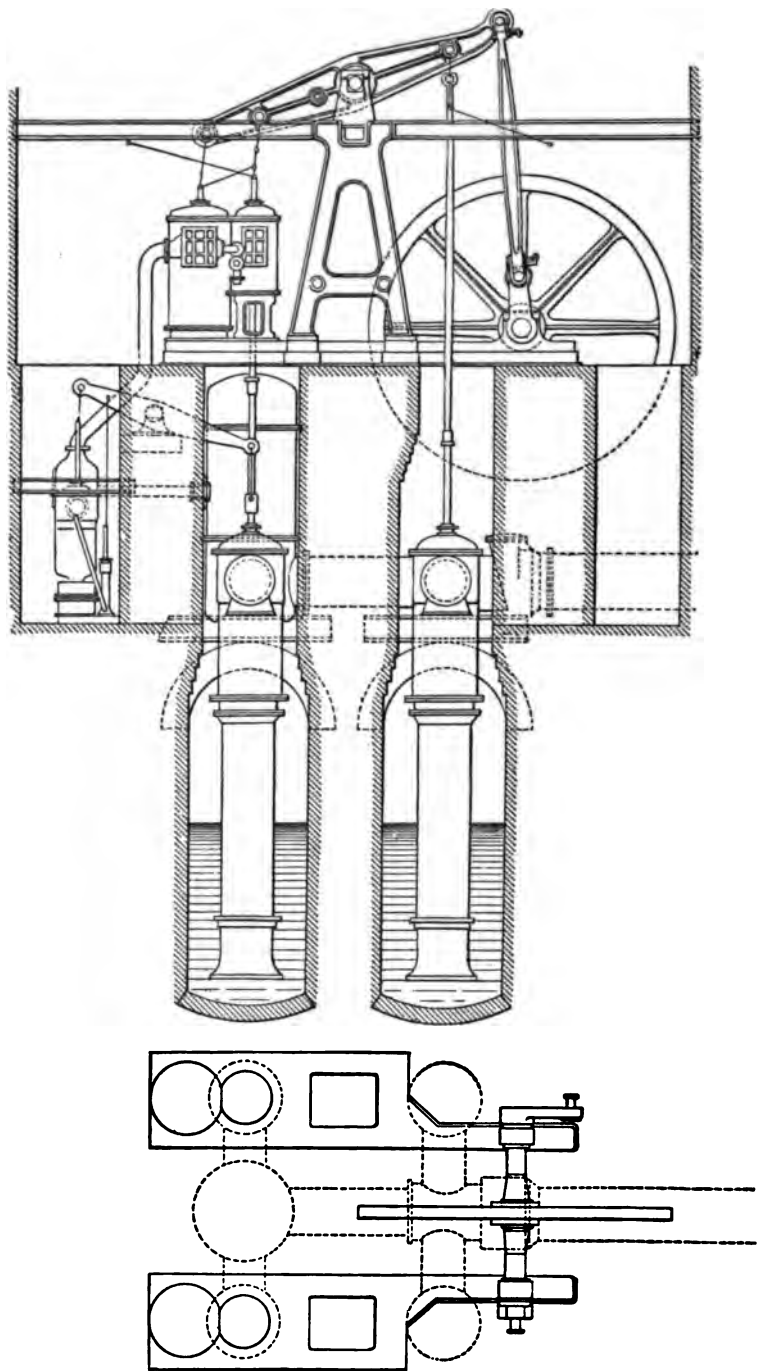
Figs. 669.—Easton & Anderson; Buenos Ayres Water-works: Pumping Engine.   Scale 1/128th.

Each of the service-pumps, figs. 668, is of the single-acting lift type, have a 41-inch barrel, with 46 inches of stroke; drawing through a 36-inch pipe from the pump-well beneath, and discharging through a 27-inch pipe into the air-vessel and 3-feet main, between the engines forming each pair. The four pumps of each pair of engines have a joint discharge-capacity of 876 gallons per revolution, and the average volume in the air-vessel is 1290 gallons.

The steam is supplied from four boilers 7 feet in diameter, 23 feet long; having two furnace-tubes 2¾ feet in diameter, fitted each with six Galloway pipes, and terminating in eighty-eight 3-inch flue-tubes 6 feet long. In normal conditions, two boilers with one pair of engines work at a time. The engines and pumps have been guaranteed to give a duty of 100 millions of foot-pounds in water raised per hundredweight of coals.

Chapter XXXIV.
COMPOUND BEAM PUMPING STEAM ENGINES.

CONSTRUCTED BY MESSRS. JAMES SIMPSON & CO., LONDON, FOR THE LAMBETH WATER-WORKS, THAMES DITTON.

(Cylinders 21 inches and 36 inches in diameter, stroke 5½ feet.)

The Ditton pumping engines were designed each to pump 420,000 gallons of water per hour 35 feet high, to supply the new filter beds.

The leading dimensions and the performance of these pumping engines, constructed and erected in 1881, by Messrs. Simpson & Co., have already been noticed as the J engines, vol. i. p. 535. The general design and arrangement of the engines and pumps are shown in figs. 670, 671, and 672. There are two independent engines, side by side, in the same house. Each engine is compound, of which the first and the second cylinders with separate beams are connected to two cranks at right angles on the main shaft. The steam exhausted from the first cylinder passes through Mr. E. A. Cowper's reheater or superheater on its way to the second cylinder. The cylinders and the reheater, excepting the covers of the first cylinder and the receiver, are thoroughly steam-jacketed with steam direct from the boilers, and the condensation-water from the jackets is returned by gravitation to the boilers. The steam is distributed by slide-valves, one valve at the top and one at the bottom, with expansion-plates on the back, the expansion in each cylinder being adjustable by hand. The valves are driven by a lay-shaft, which is worked from the crank-shaft by means of bevel gear. A jet-condenser is used.

Two low-lift plunger-pumps are worked direct from each beam—one from each arm of the beam; and four pumps by each engine, which discharge into a stand-pipe, from which the water passes into the reservoir.

The base-plate of each cylinder is of 1⅛-inch metal. It stands 8 inches high, and rests on border flanges, 1¼ inches thick.
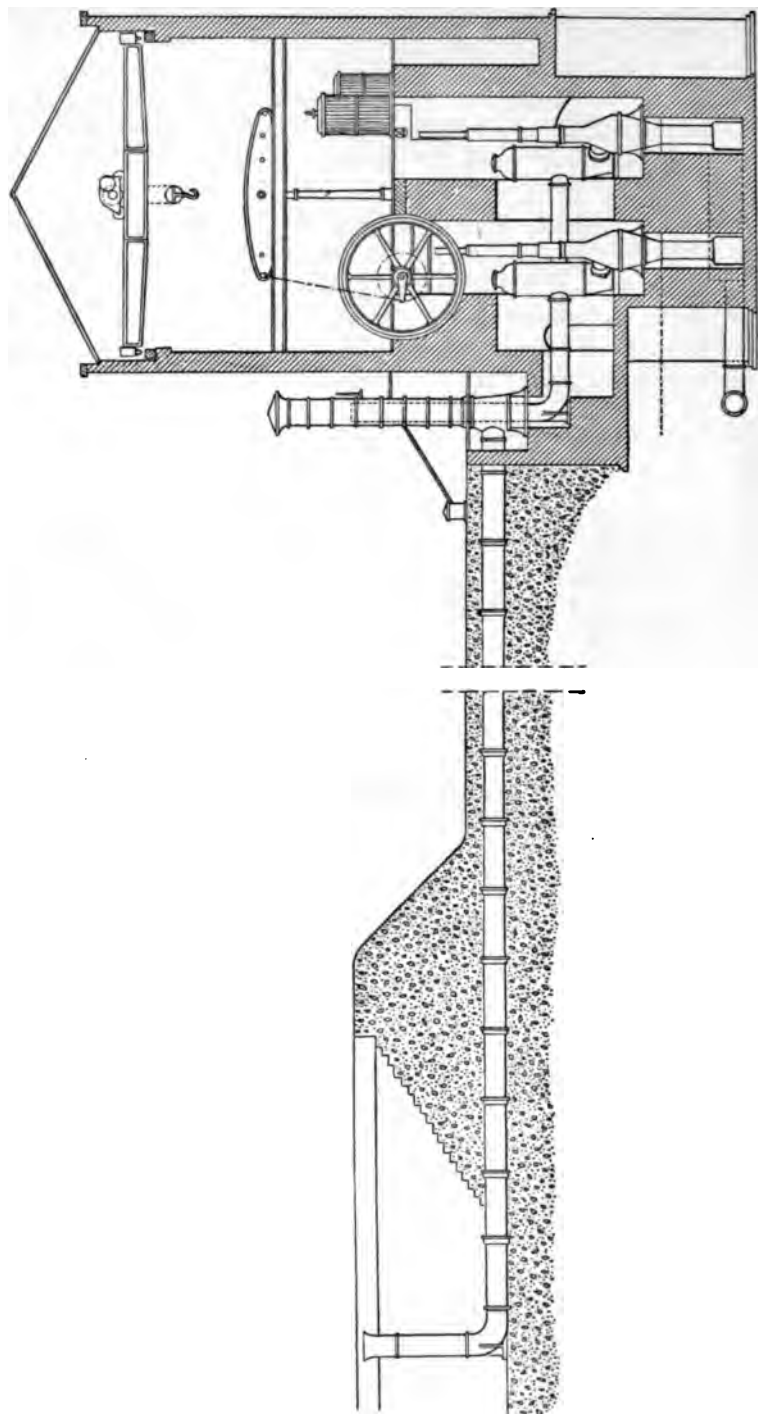
Fig. 670.—James Simpson & Co.: Compound Beam Pumping Steam Engine (J Engine), Lambeth Water-works, Thames Ditton. Sectional Views of Engine and Reservoir. Scale 1/256th.

The first and second cylinders are respectively 21 inches and 36 inches
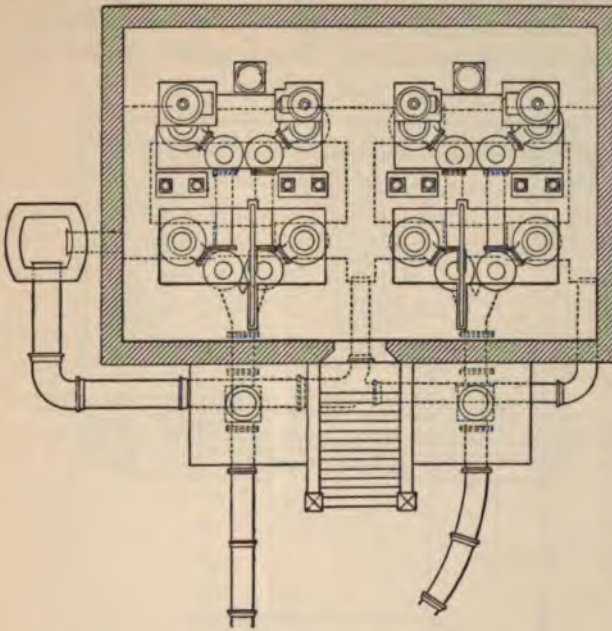
Fig. 671.—J. Simpson & Co.: Pumping Engines, Thames Ditton. Plan. Scale 1/256th.
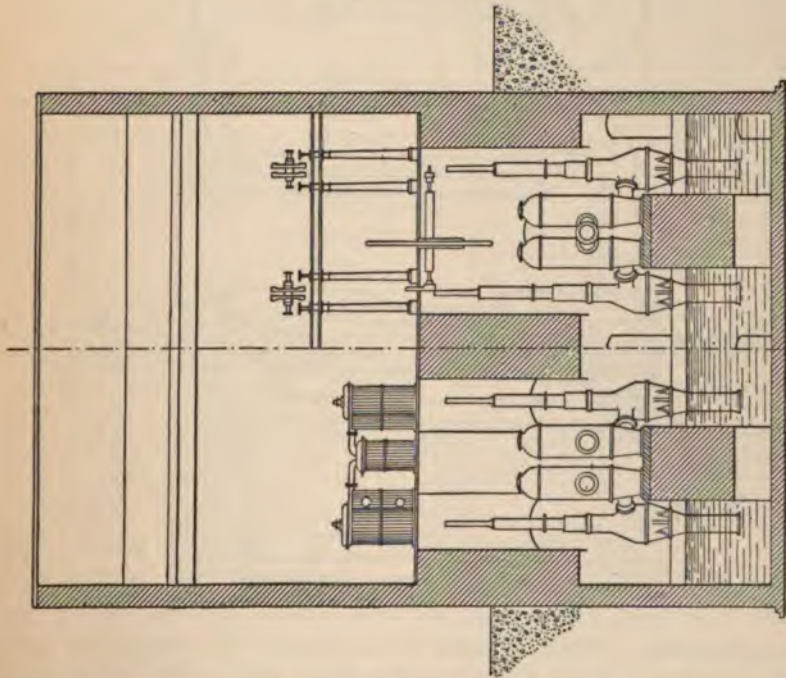
Fig. 672.—J. Simpson & Co.: Pumping Engines, Thames Ditton. Cross Sections. Scale 1/256th.

in diameter, of $1\frac{1}{8}$-inch metal, with a stroke of $5\frac{1}{2}$ feet, having the capacity-ratio 1 to 3. The jackets and covers also are of $1\frac{1}{8}$-inch metal.

In the first cylinder the jacket is cast solid with the cylinder.   In the
second, they are separate castings, the barrel being inserted as a liner, with
a flanged base.   The main valves of the first cylinder have 4 inches of
travel, ⅜ inch lap, and ⅛ inch lead.   Those of the second cylinder have
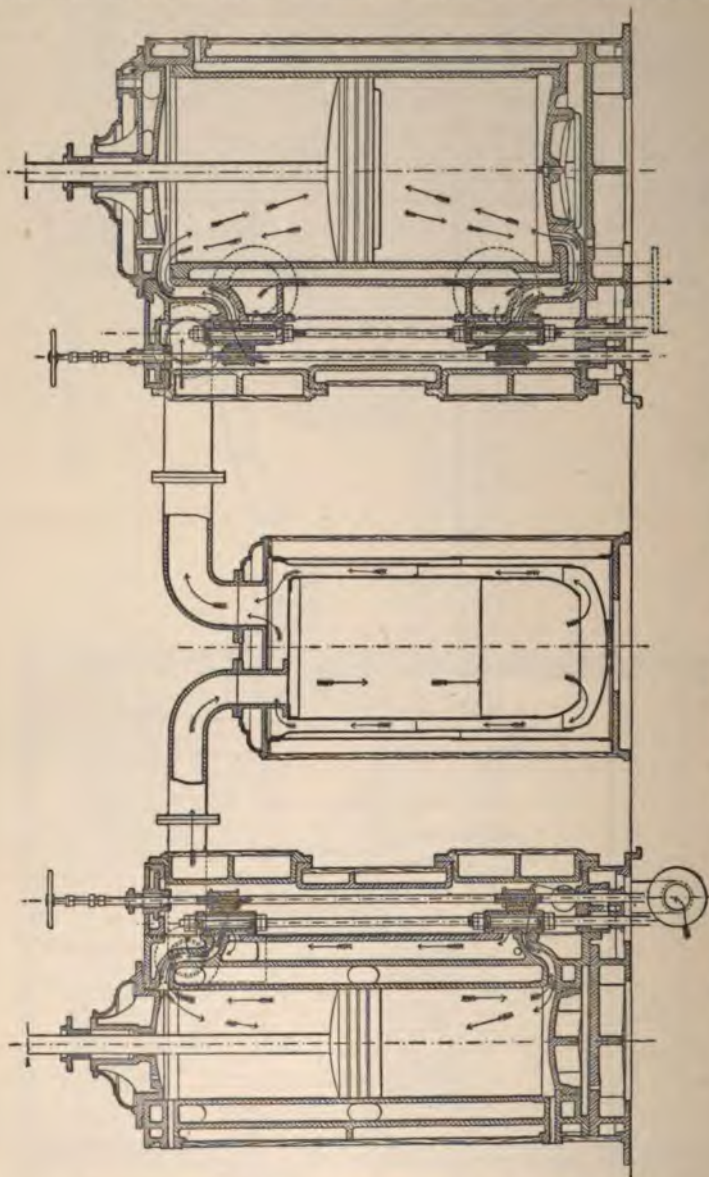
Fig. 673.—J. Simpson & Co.: Pumping Engines, Thames Ditton.   Cylinders and Reheater.   Scale 1/36th.

5½ inches of travel, ⅝ inch lap, and ⅜ inch lead.   The expansion-valves
have 5½ inches of travel.   The steam-ports of the first cylinder are
10 inches by 1½ inches, and the exhaust-ports are 10 inches by 2 inches;
and those of the second cylinder are 21 inches by 2½ inches, and 21 inches

by 3 inches. Their areas are respectively $1/23.1$ and $1/17.3$ part of the first cylinder-area; and $1/19.4$ and $1/16$ part of the second cylinder-area.

Steam is brought to the first valve-chest by a 5-inch cast-iron pipe, of ½-inch metal; and is exhausted by a 6-inch pipe, of ½-inch metal, into the reheater. The reheater, fig. 673, is of plate-iron, 2 feet 10 inches in diameter, 5½ feet high, with an inner cylinder 2 feet 7 inches in diameter, forming with the outer cylinder a jacket-space for steam from the boiler; and a third cylinder, 27 inches in diameter, concentric, into which, at the upper end, the steam is exhausted. The steam descends and passes out at the lower end into the interspace between the jacket and the exhaust-cylinder, in which it ascends, and from which, at the upper end, it is conducted by an 8-inch cast-iron pipe, of $9/16$-inch metal, to the second cylinder. The steam is exhausted into the condenser by a 9-inch pipe, of ⅝-inch metal.

The condenser, figs. 674, is a tall cylinder, of cast iron, 18 inches in diameter, 10 feet 11 inches high, inside, of ⅞-inch metal. The steam enters at the top, and the injection water at the bottom, through a 3-inch cast-iron pipe, which is carried up inside the condenser to a level about 2 feet 7 inches below the top, and terminated with a copper rose. The condensed steam and water fall to the bottom. The air-pump, figs. 674, to which the water is passed through a 9-inch pipe, is 22 inches in diameter, with a stroke of 28½ inches. It is of cast iron, 1 inch thick; and the hot-well is cast solid with it, 28 inches in diameter. The

Figs. 674.—J. Simpson & Co.: Pumping Engine, Thames Ditton. Condenser, Air-pump, and Feed-pump. Scale 1/40th.

air-pump has a foot-valve and a bucket-valve of india-rubber, 17½ inches in diameter, ⅝ inch thick, on a gun-metal seat. The bucket-rod is of wrought iron, 2 inches in diameter, and is fitted with a crosshead, detailed in fig. 675, at the upper end, connected by two side rods with the main beam. It is prolonged upwards, with a cotter junction to form the ram of the feed-pump, 2¼ inches in diameter, which is worked upwards, and has the stroke of the pump. The pump is capable of delivering double the quantity of feed-water normally required.

The pistons, fig. 676, are of cast iron, one piece, hollow, of ⅞-inch metal. The first piston is 8 inches thick, and the second is 8 inches thick, reduced to 7 inches at the circumference. The unusually great thickness of the first piston is designed to ensure that no steam shall leak past the
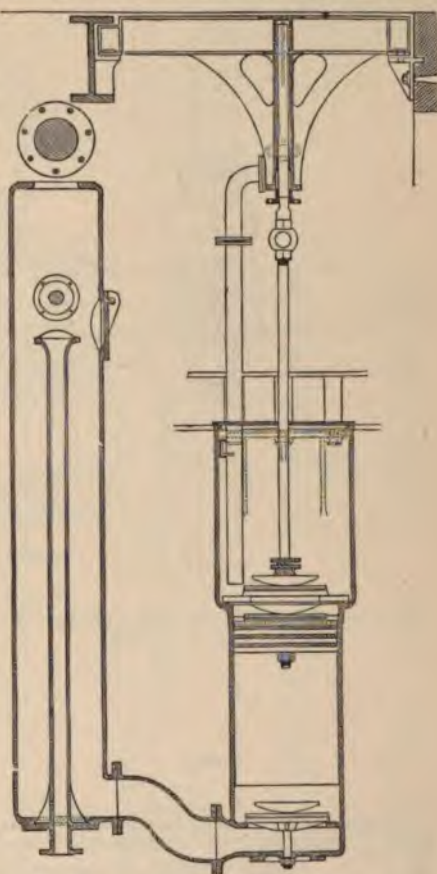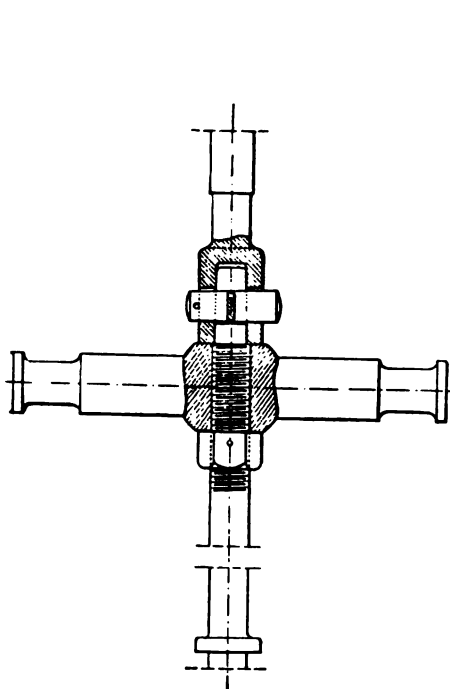
Fig. 675.—Simpson's Pumping Engine: Crosshead on Air-pump Rod. Scale 1/10th.
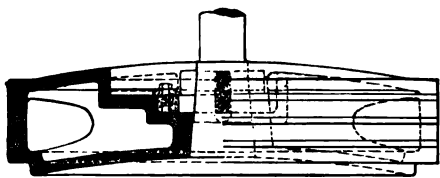
Fig. 676.—J. Simpson & Co.: Pumping Engine, Thames Ditton. Second Piston. Scale 1/16th.
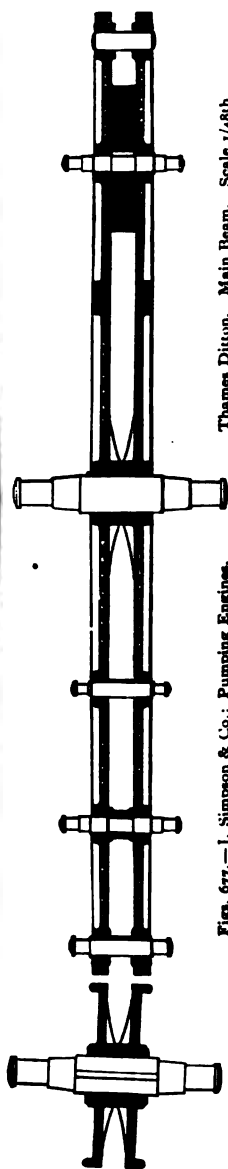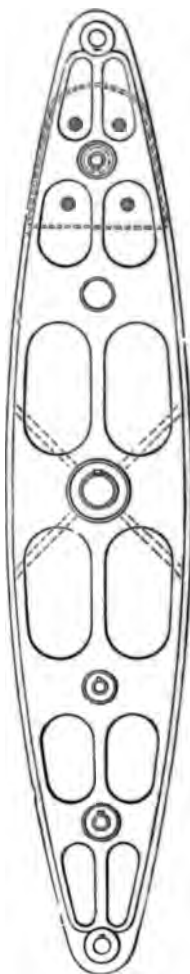
Thames Ditton. Main Beam. Scale 1/48th.

Fig. 677.—J. Simpson & Co.: Pumping Engines,

piston, and for uniformity with the second piston. Each piston is packed with three Ramsbottom steel rings, ¼ inch wide, 5/16 inch thick. Each piston-rod is of steel, 3¾ inches in diameter, and is expanded conically at the lower end, to take the piston, into which it is cottered. A crosshead,
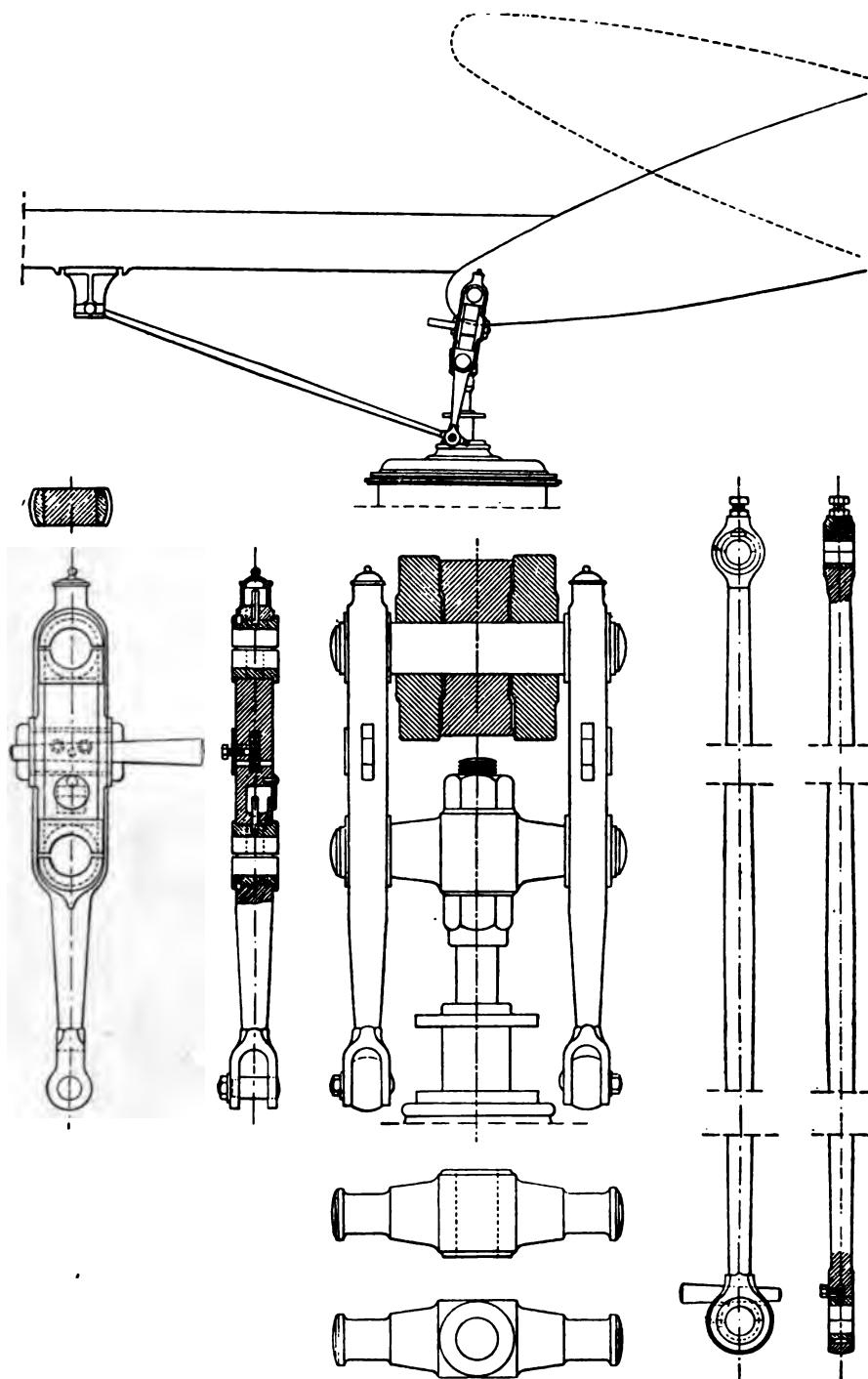
Figs. 678.—J. Simpson & Co.: Pumping Engine, Thames Ditton. General View and Details of Parallel Motion and Crosshead. Scale, General View, 1/48th; Details, 1/16th.

figs. 678, is fastened by double-nuts on the upper end of the piston-rod, having two journals 3½ inches in diameter, 4 inches long, 19 inches apart between centres. The eye of the crosshead is 7½ inches deep.

The main beam, figs. 677 and 678, is of cast iron, in two flitches, 6½ inches apart. The half-beams are panelled on the outer sides, of 1¾-inch metal in the panels, thickened about the gudgeons, and flanged at the upper and lower edges. The length of the beam is 18 feet 10.905 inches, or 4.905 inches in excess of the distance apart of the axes of the cylinder and the crank-shaft, which is 18½ feet. The half-beams are united by being keyed on the gudgeons. The gudgeons are of wrought iron; the main gudgeon is 9½ inches in diameter in the beam, and has 6-inch journals. A heavy counterweight, shown in figs. 677 and 678, is bolted to the beam to balance the piston and other parts.

The design of the parallel-motion, which is of wrought iron, is shown in figs. 678, in which the half-beam has 9 feet 5.4525 inches of radius, the radius-rod is 8 feet 4³⁷/₆₄ inches long, and the pair of links are 3 feet 2¹⁹/₄₀ inches long, divided by the piston-rod crosshead into unequal lengths respectively 18 inches and 20¹⁹/₄₀ inches. Of the links, the upper and middle bearings are 3½ inches in diameter, 4 inches long; and the lower ends are fitted with 2-inch pins to take the radius-rods.

The connecting-rod, figs. 679, of wrought iron, is 16 feet 1 inch long, or 5.85 times the length of the crank; with brass bushes, butt, strap, gib,
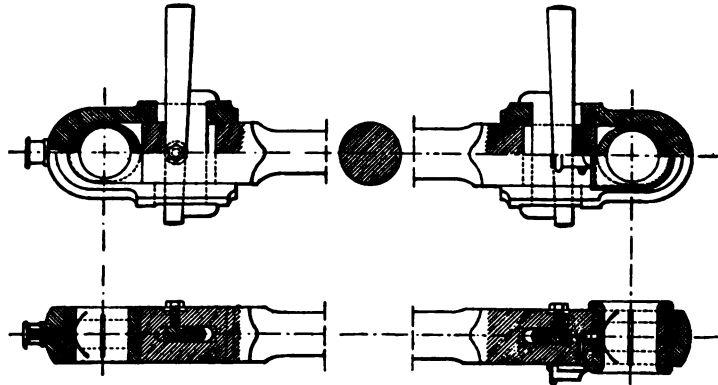
Figs. 679.—J. Simpson & Co.: Pumping Engines, Thames Ditton.   Connecting-rod.   Scale 1/10th.

and cotter at each end. The upper bearing for the beam is 4½ inches in diameter, 4½ inches long; the lower bearing for the crank-pin is 4½ inches in diameter, 6 inches long. The body of the rod is round in section, 3¾ inches in diameter at the upper end, 4 inches at the lower end, swelled to 5½ inches at the mid length.

The crank-shaft, fig. 680, is of wrought iron, 10 inches in diameter, increased to 10¾ inches for the fly-wheel; the journals are 8½ inches in diameter, 11 inches long, 10½ feet apart between centres; the shaft is 8½ inches in diameter, 8½ inches long in the centre of the crank. The cranks, one on each end of the shaft, of wrought iron, have a radius of 2 feet

9 inches. The centre has 3 inches of metal round the shaft. The body of each crank is 4½ inches thick. The crank-pin, of wrought iron, is driven in with a collar bearing, and riveted over. The journal is 4½ inches in
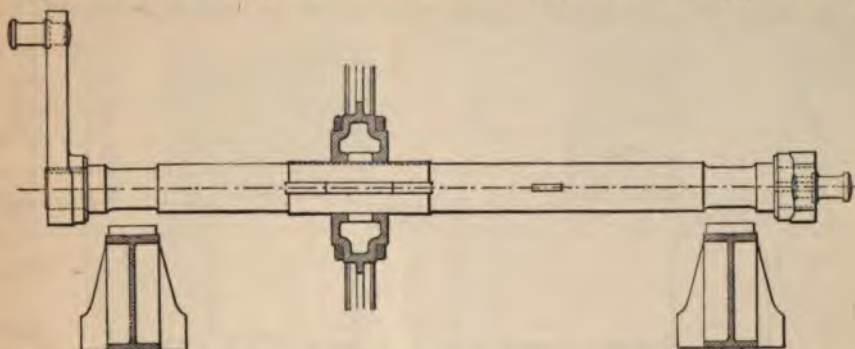
Fig. 680.—J. Simpson & Co.: Pumping Engine, Thames Ditton. Crank-shaft. Scale 1/40th.

diameter, 6 inches long. The centres of the length of the crank-pin journals are 21 inches beyond the centre of the shaft journal; and the total transverse distance apart of the crank-pins is 14 feet, which is the distance
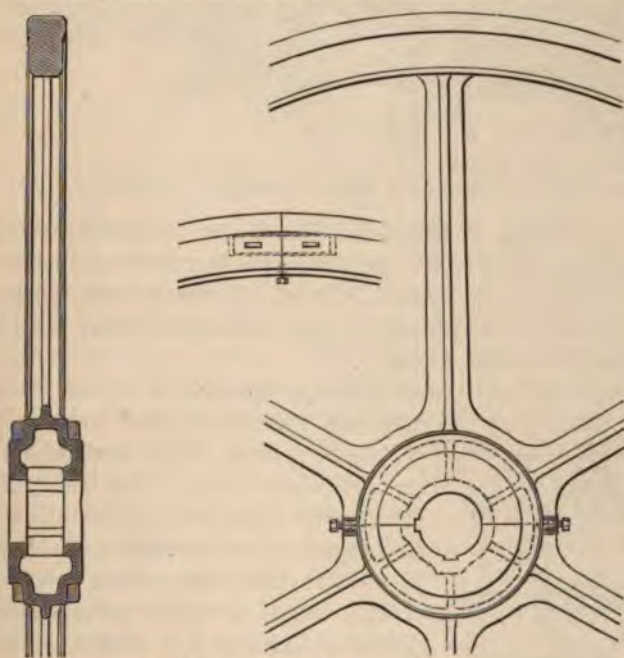
Figs. 681.—J. Simpson & Co.: Pumping Engine, Thames Ditton. Fly-wheel. Scale 1/32d.

apart of the longitudinal centre-lines of the first and second parts of each engine.

The fly-wheel, figs. 681, is of cast iron, 14¼ feet in diameter, cast in halves, dowelled together at the rim, rung together at the centre. The rim

is nearly rectangular in section, 6¼ inches wide by 9½ inches. The centre is cast hollow, and is bored to 10½ inches in diameter, with 12 inches length of bearing on the shaft, on which it is fastened with two keys. There are six arms, of a cruciform section, 7 inches by 6½ inches at the centre,
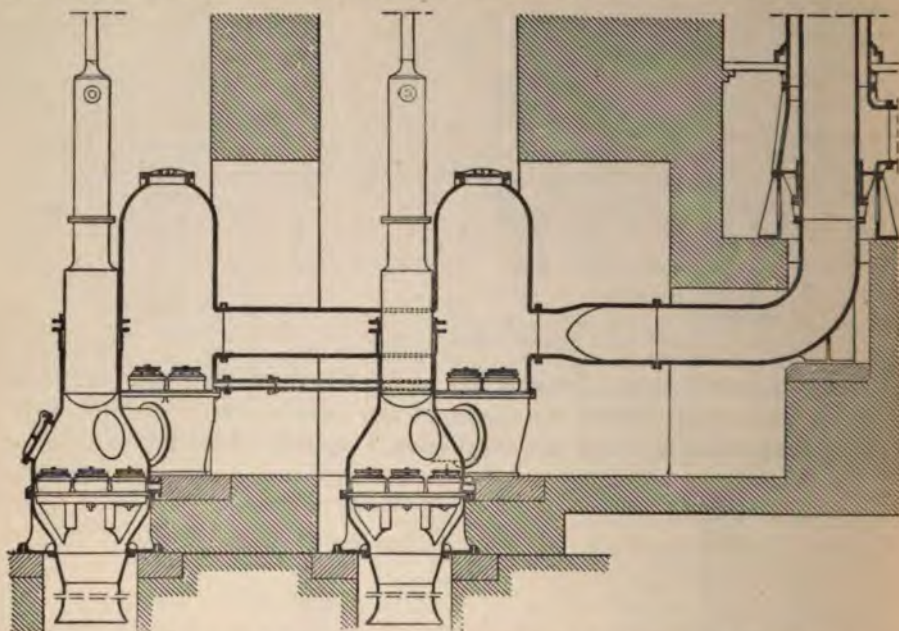
Fig. 682.—J. Simpson & Co.: Pumping Engine, Thames Ditton. Service-pumps. Scale 1/96th.

6 inches by 3¼ inches at the rim. The centre is united by two wrought-iron rings shrunk on, one at each side, 24 inches in diameter internally, 3 inches by 2 inches in section. Steadying screws are inserted between the arm-segments at the centre, to keep the segments in position laterally whilst the rim-dowels are keyed up.

The plunger of each service-pump, fig. 682, is of cast iron, hollow, of
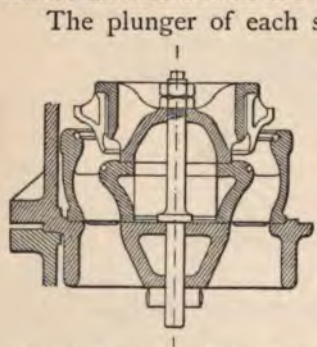
Fig. 683.—J. Simpson & Co.: Section of a Pump-valve and its Seat. Scale 1/16th.

1⅛-inch metal; 2¼ feet in diameter, with a stroke of 4 feet. It is worked by two 4-inch wrought-iron rods. The body of the pump is of cast iron, of 1¼-inch metal, and is developed to a diameter of 4 feet 10 inches to receive the foot-valves, seven in number, double beat, of gun metal, 17 inches in diameter, having 1⅛ inches of lift, fig. 683, arranged on a diaphragm plate of cast iron, fastened between the flanges of the pump. Each pump is fitted with an air-vessel, of 1¼-inch metal, 4 feet in diameter, 9 feet high, fitted with four delivery valves, into which the pump delivers the water. The air-vessels of each pair of pumps are connected by a 22-inch pipe

of 1⅛-inch metal, from the second in order of which the water passes off and meets the current from the neighbouring pair of pumps. The two currents are united in a 27-inch main, from which the water rises into a 27-inch stand-pipe, of ⅞-inch metal, over the top of which it falls into an outer pipe, 40 inches in diameter, of 1⅛-inch metal, encasing the stand-pipe, from which it flows through a 27-inch syphon-pipe to the reservoir, ending in a vertical limb which rises nearly to the level of the embankment.

The lift of the pumps is 35 feet 1½ inches from the mean level of the canal to the top of the stand-pipe. According to the average results of a trial made by Mr. John Taylor, engineer to the Water Company, in September, 1881, lasting 8¼ hours, the engines made a mean speed of 21.55 turns per minute for 34.974 feet of lift, with 59.26 lbs. working pressure in the boiler, 27.72 inches of vacuum, 30.41 inches of the barometer, 973,750 gallons of water lifted per hour; 238.77 indicator horse-power of both engines; 172.011 horse-power in water lifted by both engines, or 72 per cent of the indicator power; Welsh coal consumed, 27.25 cwts., making 100 pounds of ashes; duty per 112 pounds of coal, 103.112 millions of foot-pounds; 1.55 pounds of coal per indicator horse-power; 2.15 pounds of coal per effective horse-power. Steam was supplied by four Cornish boilers, 5½ feet in diameter, 27 feet long, each having a 3-feet furnace-tube, with a grate area of 17½ square feet. The quantity of water pumped was determined by the measurement of the reservoir into which the water was delivered.

A few days later a trial of 24 hours' duration was conducted by Mr. E. A. Cowper. The actual quantity of water raised was measured in the reservoir. Nixon's Navigation Coal was used, and steam was supplied from three of the Cornish boilers already noticed. The following are the leading results:—Indicator horse-power of both engines, 240.119 I.H.P.; effective horse-power in water delivered, 174.71 H.P.; efficiency, 72.8 per cent; volume of water delivered, 94.04 per cent of their capacity; coal per indicator horse-power per hour, 1.605 pounds, and per effective horse-power, 2.206 pounds; duty, 100,539,103 foot-pounds per cwt. of coal; coal per square foot of fire-grate per hour, 7.14 pounds; water supplied to the boilers per indicator horse-power per hour, 13.40 pounds; water per pound of coal, 8.35 pounds. In addition, the coal supplied the heat given up to the steam-jackets, from which the condensed steam was returned unmeasured to the boiler. By separate measurement, the steam so condensed has been ascertained to be from 2 pounds to 2.1 pounds per horse-power per hour; and adding this quantity, the total water consumed per indicator horse-power per hour would amount to, say, 15.5 pounds.

The performance of this pumping engine, as a steam engine simply, has been investigated, vol. i. page 535. By the results of Mr. Mair's test-trials, the virtual identity of the quantities of steam as brought into evidence passed through the cylinders by the indicator diagram, and as directly measured from the boiler, was established. They were respectively 13·01 pounds and 13·17 pounds.

The following are the weights of the principal pieces:—

	Tons.	Cwts.	Qrs.
1 fly-wheel	4	7	2
1 crank-shaft and cranks	2	3	2
1 first cylinder, cover, and bed-plate	4	19	1
1 second cylinder do. do.	7	17	0
1 connecting-rod	0	12	2
1 beam and gudgeons	10	12	1
Total weight of one engine	80	5	0
Do. pumps and pipes (for one engine)	113	5	0

CHAP. XXXV.—OTHER BEAM PUMPING STEAM ENGINES.

CONSTRUCTED BY MESSRS. JAMES SIMPSON & CO., LONDON.

WOOLF COMPOUND BEAM ENGINE, LAMBETH WATER-WORKS, SURBITON.

(Cylinders 22 inches and 37 inches in diameter; strokes 4 feet 7 inches and 6½ feet.)

A Woolf compound beam pumping engine, fig. 684, was erected at Surbiton Pumping Station of the Lambeth Water-works; the first and second cylinders being together at the same end of the beam, opposite the crank end. The first cylinder is 22 inches in diameter, with a stroke of 4 feet 7 inches; the second cylinder is 37 inches by 6½ feet. The ratio of the volumes of the cylinders is as 1 to 4.02. The cylinders are thoroughly steam-jacketed, with steam direct from the boilers. Each cylinder has a main-valve, and an expansion-valve on the back of it, and the second cylinder is provided with independent adjustable exhaust-valves. Two double-acting four-valve pumps are worked direct from the beam, one under each arm. The piston of the pump at the cylinder end is 13 inches in diameter, and that of the pump at the main-shaft end is $17^{1}/_{32}$ inches in diameter, both having a stroke of 3 feet $7^{7}/_{16}$ inches. The capacity of both pumps, deducting piston-rods, for one revolution, is 109 gallons. The principal results of a trial made in February, 1884, by Mr. John Taylor, were as follows:—Steam was supplied from three boilers, of which two were Lancashire double-furnace tube boilers, 6½ feet in diameter, 27 feet long; with 30-inch tubes, fitted with four Galloway pipes; and the third was a Cornish boiler, 3½ feet in diameter, 14 feet long, with a 2-feet furnace tube. Steam of 61 lbs. working pressure was supplied from the Lancashire boilers to work the engine; steam of 101 lbs. was supplied from the Cornish boiler to charge the jackets. Nixon's Navigation Welsh coal was used. The leading average results were as follows:—The head in the pumps was 187.65 feet; 27 revolutions were made per minute; steam was cut off in the first cylinder at 33 per cent; 193.6 indicator horse-power was exerted; 167.6 effective horse-power in water lifted was obtained, or 86.6 per cent of the indicator power; with a duty of 124.27 millions of foot-pounds per 112 pounds of coal; 2090 pounds of coal was consumed in the two Lancashire boilers,

and 298 pounds in the Cornish boiler; 1.54 pounds was consumed per indicator horse-power per hour, and 1.784 pounds per effective horse-power.
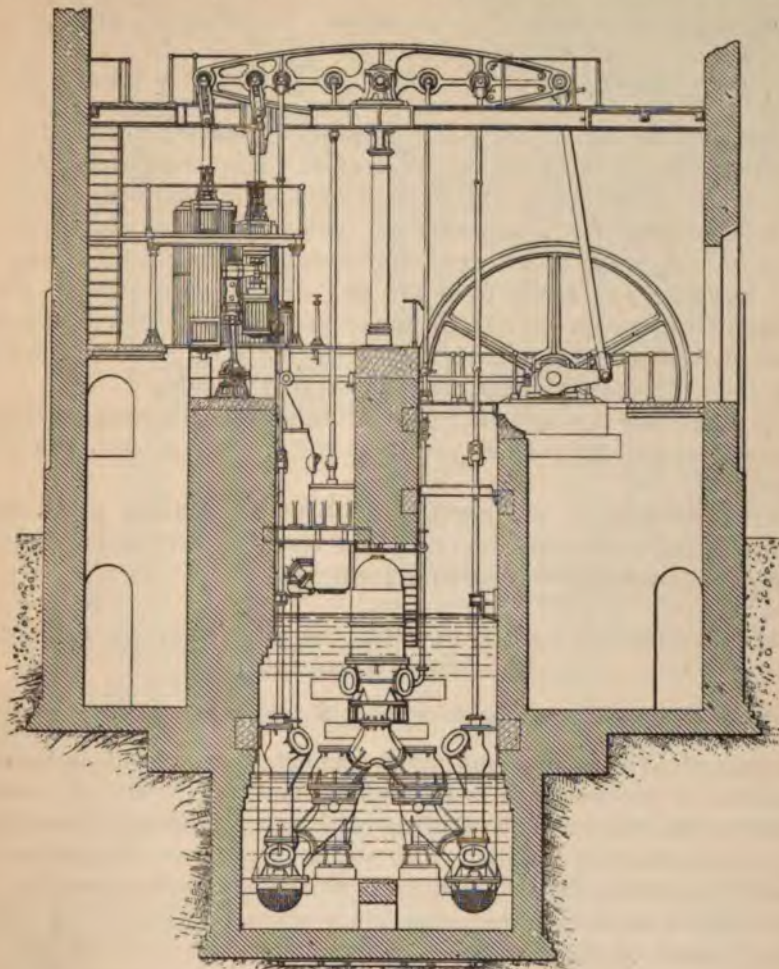
Fig. 684.—J. Simpson & Co.: Lambeth Water-works. Woolf Compound Beam Pumping Engines, Surbiton Station. Scale 1/144.

The heat obtained from one pound of coal was—from the jacket boiler, 7500 units; from the larger boilers, 11,682 units.

WOOLF COMPOUND BEAM PUMPING ENGINE, CHELSEA WATER-WORKS, SURBITON.

(Cylinders 30 inches and 40 inches in diameter; strokes 5½ feet and 8 feet.)

A pair of Woolf beam pumping engines, each working one pump, were constructed by Messrs. Simpson & Co. for the Chelsea Water-works, at their Surbiton Station, where they were set to work early in 1866. The cylinders are together at one end of the beam, and the connecting-rod is

at the other end. The pump is worked by a rod off the beam, connected near the end of it.

Diameter of first cylinder......... 30 inches.   Stroke 5½ feet.
   Do.   second do. 46   „   Do. 8   „
   Do.   pump................. 18½ „   Do. 6 feet 11 inches.

The first cylinder has at each end an ordinary main slide-valve, and an expansion-valve working on the back of it. The expansion-valves are driven direct by the beam. The second cylinder is fitted with double-beat equilibrium-valves for admission and exhaust, worked by cams, the admission-cams being so arranged that steam may be cut off at any part of the stroke. The steam from the first cylinder is exhausted into an unjacketed receiver on its way to the second cylinder. By means of the receiver it is practicable to cut off the steam early in the second cylinder, and to limit the range of temperature in the first cylinder.

The pumps are double-acting four-valve pumps: each pump having two suction-valves and two delivery-valves, one of each at each end of the pump.

The usual duty of the engines is about 83 millions per hundred-weight of small coal: dependent of course on the quality of the coal. On a special trial, this duty was much exceeded.

WOOLF COMPOUND BEAM PUMPING ENGINE, WEST MIDDLESEX WATER-WORKS, HAMMERSMITH.

(Cylinders 29 inches and 3 feet 11½ inches in diameter; strokes 5 feet 5 inches and 8 feet.)

A pair of Woolf compound beam engines were erected at the West Middlesex Water-works, Hammersmith, numbered 7 and 8, arranged similarly to the first Surbiton pumping engine above noticed. The cylinders are completely steam-jacketed with steam direct from the boilers, and the second cylinders have separate steam-valves and exhaust-valves. The exhaust-valves are double-beat equilibrium-valves, one for the top and one for the bottom of the cylinders. There is one service-pump with four valves, for each engine, worked from the crank end of the beam.

It was required by the contract that the engines were each to be capable of pumping 3,456,000 gallons in 24 hours; and the duty was to be not less than 96.4 million foot-pounds per 112 pounds of coal, 5 per cent being previously deducted from the pump-displacement.

The cylinders are shown in section, in fig. 685. The first cylinder is 29 inches in diameter, with a stroke of 5 feet 5 inches. The second cylinder is 3 feet 11½ inches by 8 feet. The capacities are as 1 to 4. Steam is cut off in the first cylinder at 33 per cent; and there are in all 11.1 expansions. The main-pump is $17^{15}/_{16}$ inches in diameter, with a stroke of 8 feet. These engines were subjected to 24 hours' trial in February, 1883, by Mr. Thomas Hack, engineer to the company. Steam was supplied from three Cornish boilers, 6 feet in diameter, 28 feet long, with a 3½-feet

furnace-tube, using Nixon's Navigation Welsh coal. The feed-water was taken from the hot-well and pumped direct into the boilers. The jacket-
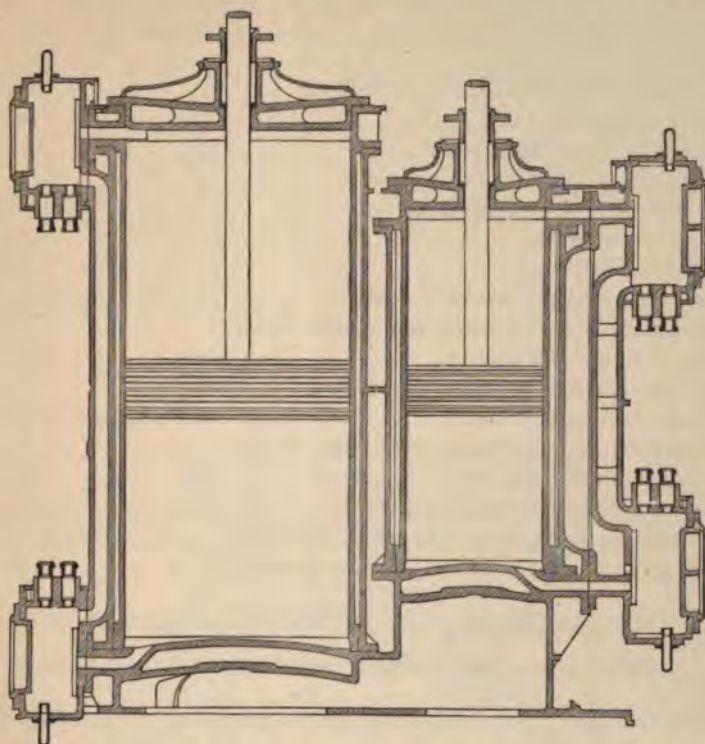
Fig. 685.—J. Simpson & Co.: Pumping Engine, Hammersmith. Cylinders. Scale 1/40th.

steam, as condensed, gravitated back to the boilers. The average results were as follows:—

	No. 7.	No. 8.
Working pressure in the boilers, per square inch	50 lbs.	50 lbs.
Revolutions per minute	18	18.3
Barometer	30 inches.	29.6 inches.
Vacuum in condensers	28.5 ,,	28.1 ,,
Temperature of injection-water	40° F.	46° F.
Do. discharge from air-pump	72° F.	77° F.
Lift of water	187.7 feet.	187.2 feet.
Indicator horse-power	206.5 H.P	206.2 H.P.
Effective horse-power, in water lifted	164.35 ,,	166.46 ,,
Do. do. per cent of indicator power	79.6 per cent.	80.7 per cent.
Coal consumed per indicator horse-power, per hour	1.53 lbs.	1.55 lbs.
Do. do. effective do. do.	1.91 ,,	1.92 ,,
Duty per 112 pounds of coal, in millions of foot-pounds	116.1	115.5
Gallons pumped per hour after deducting 5 per cent from the displacement	173.371	176.080

As the pistons and the valves of the service-pumps were proved to be

perfectly tight, Messrs. Simpson give the results as follows, without making the formal deduction of 5 per cent of displacement:—

	No. 7.	No. 8.
Grate-area per boiler	15.75 sq. ft.	15.75 sq. ft.
Total grate-area	47.25 ,,	47.25 ,,
Heating surface per boiler	571 ,,	571 ,,
Total heating surface	1713 ,,	1713 ,,
Grate-area per indicator horse-power	.23 ,,	.23 ,,
Heating surface per indicator horse-power	8.3 ,,	8.3 ,,
Coal per square foot of grate-area, per hour	6.67 lbs.	6.76 lbs.
Temperature of feed-water	71° F.	75°.5 F.
Working pressure in boilers	50 lbs.	50 lbs.
Feed-water evaporated per pound of coal	9.54 lbs.	9.53 lbs.
Water evaporated, including condensation-water from jackets, per pound of coal	10.3 ,,	10.3 ,,
Feed-water per indicator horse-power, per hour	14.56 ,,	14.78 ,,
Thermal units per pound of coal	11,710 units.	11,639 units.
Thermal units per indicator horse-power, per minute, from temperature of feed-water	298 ,,	300.7 ,,
Dry steam per indicator horse-power, per hour	15.23 lbs.	15.38 lbs.
Coal per indicator horse-power, per hour, assuming coal to give up 11,000 units of heat per pound	1.625 ,,	1.640 ,,

MACNAUGHT BEAM PUMPING ENGINES, BRIXTON.

(Cylinders 24 inches and 32 inches in diameter; strokes 3 feet and 6 feet.)

Two MacNaught beam compound steam pumping engines, fig. 686, were erected at the Brixton Pumping Station of the Lambeth Water-works. The depth of foundations was limited, as the engines were to be placed in an extension of one of the existing engine-houses, and consequently the width also was fixed. For the sake of compactness, comparatively to the engines on cranks at right angles, Messrs. Simpson had recourse to the MacNaught system of compound engines, the first and the second cylinders being placed one under each arm of the beam; the second cylinder being under the end of one arm, and the first cylinder midway along the other arm. The pump is fixed close to the second cylinder, and strains on the beam are limited to a minimum. Parallel motion is dispensed with for the second cylinder, the crosshead working in guides. But at the first cylinder end the parallel motion is retained, the cut-off valves being worked from it. The first piston-rod is prolonged downwards to work the air-pump, together with the feed-pump and air-charging pump. The steam is condensed in a surface-condenser, one for each engine, the suction-water passing through them on its way to the pumps. The pumps are of the bucket-and-plunger type, and each pump has an independent air-vessel and delivery-main. The first cylinders are 24 inches in diameter, with a stroke of 3 feet; the second cylinders are 32 inches by 6 feet: the ratio of capacities being as 1 to 3.56. The high-lift pump is 16½ inches in diameter; the low-lift,

21½ inches, with a stroke of 4 feet ¼ inch. A trial was conducted by Mr. Taylor, of the two engines working together. Steam was supplied from three Lancashire boilers, 7 feet in diameter, 28½ feet long, with two furnace-tubes, 2¾ feet in diameter: using Nixon's Navigation coal. The
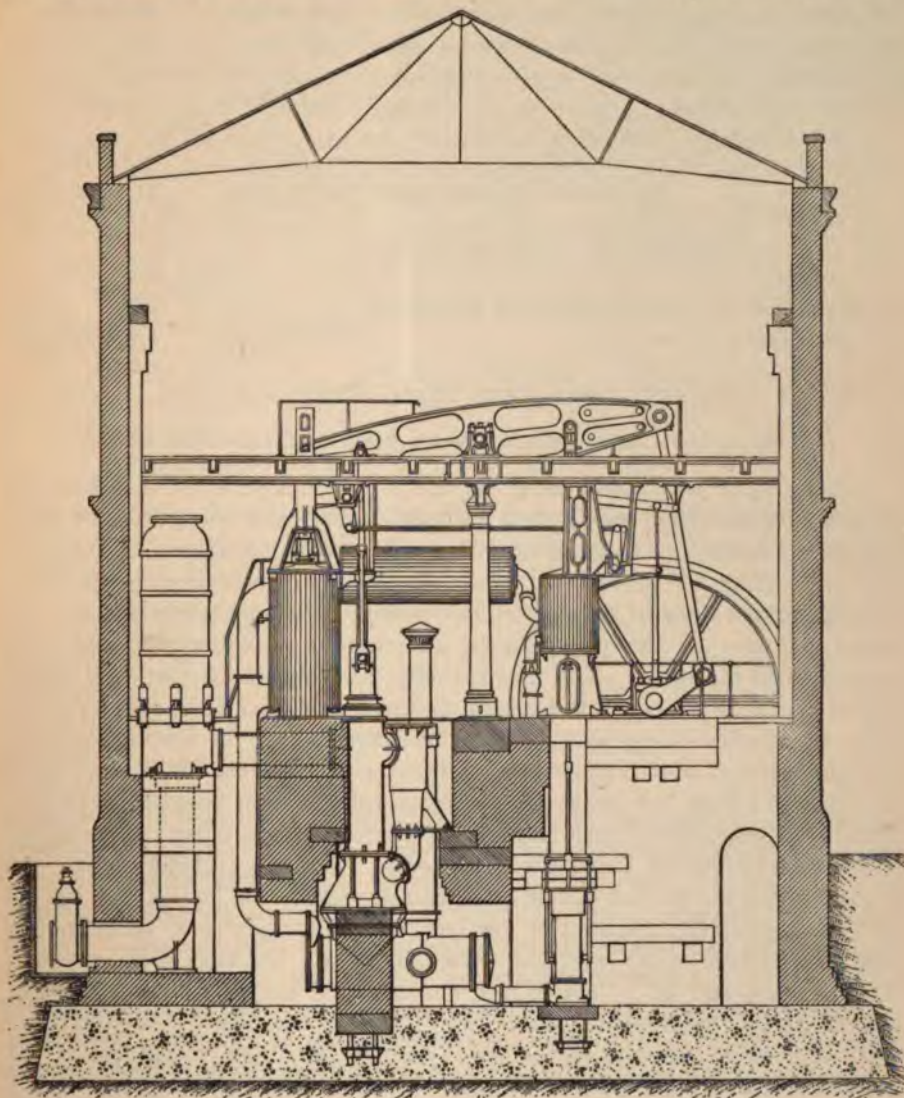
Fig. 686.—J Simpson & Co.: MacNaught Beam Pumping Engines, Lambeth Water-works, Brixton Station.
Scale 1/132d.

boilers are situated at a distance of 120 feet from the engines, and a considerable proportion of steam was condensed in the pipe though it was well clothed and drained. The leading average results of the trial were as follows:—

	High-lift Engine.	Low-lift Engine.
Duration of trial	11 hrs. 40 mins.	12 hours.
Pressure in boilers per square inch	60 lbs.	60 lbs.
Head on pump	304.9 feet.	216.6 feet.
Revolutions per minute	30.16	30.17
Barometer	29.6 inches.	29.6 inches.
Vacuum	27.9 „	27.6 „
Coal consumed	50 cwts. 1 qr. 9 lbs.	
Indicator horse-power	123.66 H.P.	150.2 H.P.
Coal per indicator horse-power, per hour	1.737 lbs.	
Effective horse-power, in water lifted	103.8 H.P.	125.1 H.P.
Do. do. per cent of indicator power	84 per cent.	83.3 per cent.
Coal per effective horse-power, per hour	2.078 lbs.	
Duty per 112 pounds of coal, in millions of foot-pounds	106.7 ft.-lbs.	
Water pumped in 12 hours, calculated in terms of the capacity of the pump	808,269 gals.	1,372,894 gals.

WOOLF COMPOUND DEEP-WELL BEAM PUMPING ENGINE, DOVER.

(Cylinders 21 inches and 34 inches in diameter; strokes 3 feet 7 inches and 5½ feet.)

This engine was constructed for the Dover Corporation Water-works. It was designed to pump 75,000 gallons of water per hour, 150 feet high, frictional resistance being additional; and it was guaranteed to consume not more than 2.6 pounds of coal per effective horse-power per hour, equivalent to a duty of 85 million foot-pounds per 112 pounds of coal: the actual delivery of the pump being taken, and no allowance made for resistance in the main. The first cylinder is 21 inches in diameter, with a stroke of 3 feet 7 inches; the second cylinder is 34 inches by 5½ feet; the ratio of capacity being as 1 to 4. The main pump, on the bucket-and-plunger system, is 20 inches in diameter, with 5½ feet of stroke. It is driven direct from the beam by means of tubular iron spear-rods, in convenient lengths, joined with flanges, working on roller-guides. The engine was tested by Mr. M. Curry for 11¾ hours. It made 18.2 revolutions per minute, against 152 feet actual lift, with a pressure of 40 lbs. per square inch in the boilers, 27 inches of vacuum, and a barometer of 29.63 inches. The temperature of the injection water was 70° F., and that of the overflow from the hot-well 96°. The water was pumped into the reservoir at the rate of 79,456 gallons per hour; 78.2 indicator horse-power was exerted, and 61 effective horse-power in water actually lifted, or 78 per cent of the indicator power; 1.92 pounds of coal was consumed per indicator horse-power per hour, or 2.46 pounds per effective horse-power; 90.1 million foot-pounds of duty was done per 112 pounds of coal, or 6 per cent over the guaranteed duty.

The absolute displacement of the pump-bucket is 74.8 gallons per turn; the quantity of water discharged by actual measurement was 72.87 gallons, making less than 2.6 per cent of slip.

WOOLF COMPOUND BEAM PUMPING STEAM ENGINE, THROCKLEY COLLIERY, NEWCASTLE-ON-TYNE.

(Cylinders 35¾ inches and 51 inches in diameter; strokes 6 feet 1½ inches and 9 feet.)

The figures on pages 320, 321 show the Woolf condensing pumping engine, constructed and erected by Messrs. James Simpson & Co., at the top of the winding shaft of the Throckley Colliery. It is the first of its type that has been erected in the North of England; the credit of which is due to Mr. John Bell Simpson, a leading advocate for economy in pumping-engine power.

The pump is double-acting, of the piston-and-plunger type, and is fixed in a sump 360 feet below the ground level. Only two valves are required for it, although the delivery is continuous. The spear-rod is made of wrought-iron tubes in 14-feet lengths, joined and guided by rollers. It is worked from the end of the beam. It is at one side of the shaft, and the rising main is at the other side.

First cylinder............ 35¾ inches diameter; 6 feet 1½ inches stroke.
Second cylinder 51   ,,   ,,   9 feet stroke.
Pump piston 24   ,,   ,,   9 ,,   ,,
    Do. plunger 17   ,,   ,,   9 ,,   ,,

The capacity-ratio of the cylinders is 1 to 3. The normal speed is 14¼ revolutions per minute, and 2500 gallons of water are delivered per minute at the normal speed.

Weight of the beam .... 24 tons.
    Do.   fly-wheel 30   ,,
Total weight of pump work 110   ,,
Weight of the heaviest piece of the pump....................... 4½ ,,
Weight of tubular wrought iron spear-rod, including bolts
    and nuts, per foot........... .... 59 lbs.

The steam is distributed in the first cylinder by two ordinary slide-valves with cut-off plates on the back; in the second cylinder the admission-valves are slide-valves with cut-off valves on them, and the exhaust-valves are rotating cylindrical valves, giving a large opening for exhaust. In consequence of the provision of special valves for exhaustion the initial condensation in the second cylinder is comparatively reduced, as the incoming steam does not pass through the same passage as the low-temperature exhaust steam. The steam is exhausted from the first cylinder into an intermediate steam-jacketed reservoir, from which it passes to the second cylinder.

In the trial conducted by Mr. Simpson, the displacement of the pump was 2408 gallons per minute; the quantity of water actually delivered was, by measurement over weirs, 2325 gallons, showing 3½ per cent of slip. The head against the pump, including frictional resistance in the rising main, was 355½ feet; and 259.4 effective horse-power in the pump was exerted. The Throckley Company's own coal was consumed at the rate

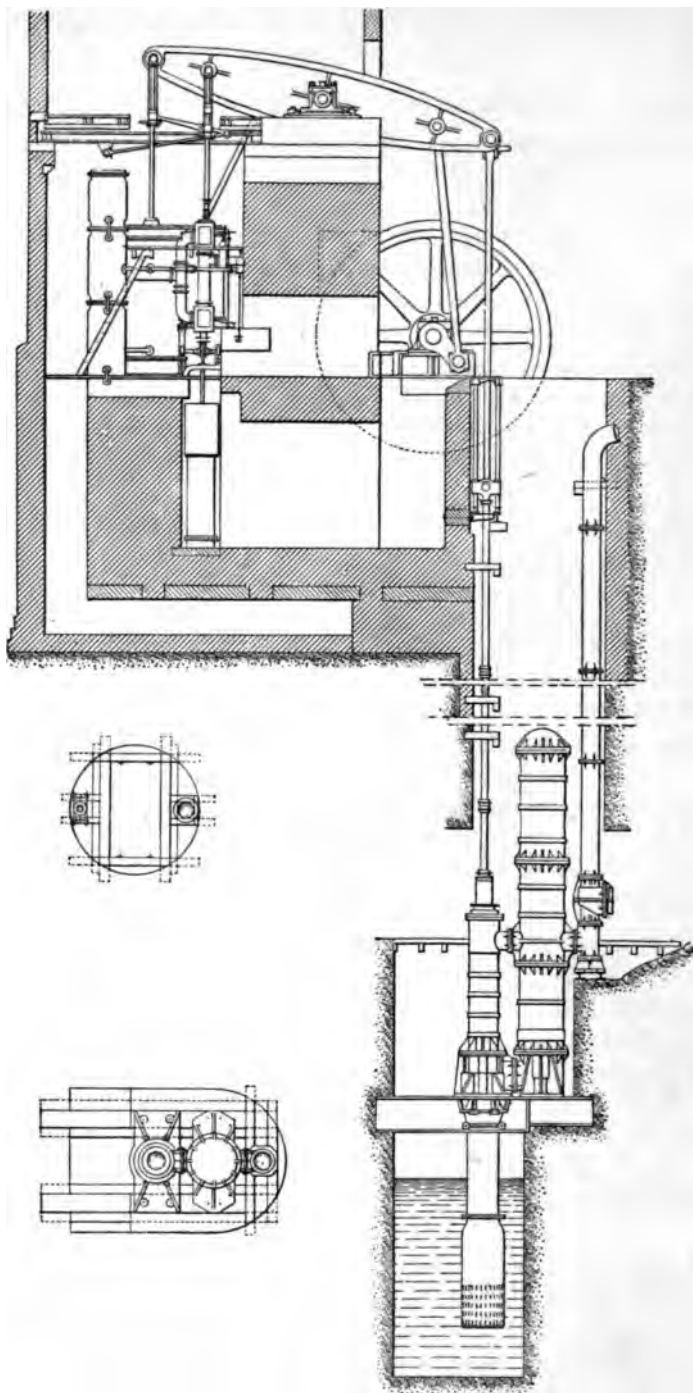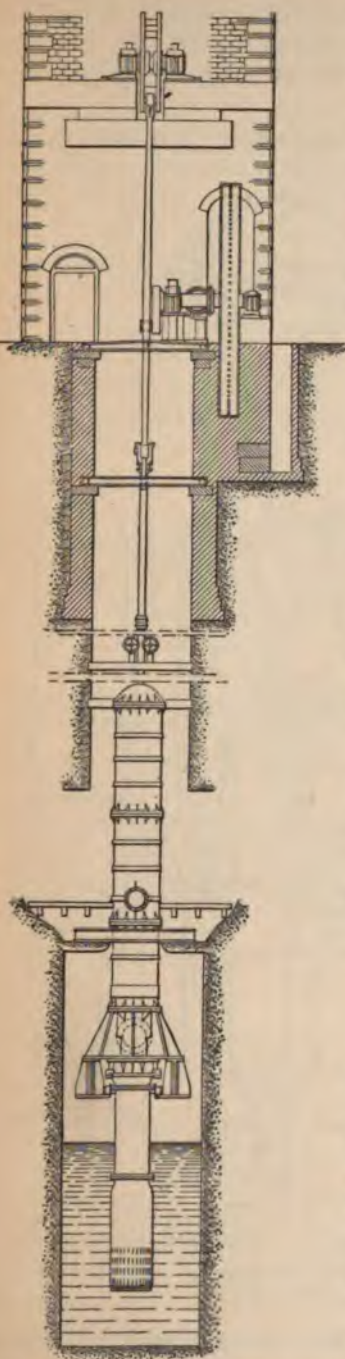Fig. 687.—J. Simpson & Co.: Woolf Compound Beam Condensing Pumping Steam Engine, Throckley Colliery.   Scale 1/192d.

of 2½ pounds per horse-power per hour, and 88.7 millions foot-pounds of duty was effected per 112 pounds of coal.

This result, 88.7 millions of duty, contrasts very favourably with that of the Hebburn Cornish engine, 61.3 millions; showing an economy of 44 per cent in favour of the Throckley engine. These comparative results agree with those found by Mr. J. G. Mair, who, by measuring the feed-water, obtained the following results with Cornish and Woolf engines:[1]—

	Thermal Units per I.H.P.	Relative Cost per I.H.P.
Cornish beam engine (Trial K)	469.5	158
Cornish bull engine (Trial P)	624.3	211
Woolf rotative engine (Trial U)	296.3	100

showing a still greater comparative saving than that shown by Mr. Simpson's experiments.

CHAPTER XXXVI.—BEAM COMPOUND ROTATIVE CONDENSING PUMPING STEAM ENGINE.

DESIGNED BY MR. E. D. LEAVITT, JUN., CONSTRUCTED BY MESSRS. J. P. MORRIS & CO., FOR THE LAWRENCE WATER-WORKS, MASSACHUSETTS, U.S.A.

(Cylinders 18 inches and 38 inches in diameter; strokes 8 feet.)

The construction and performance of this engine, fig. 689, as a steam engine simply, has already been noticed (vol. i. page 538).

The first and second cylinders are 18 inches and 38 inches in diameter, with a stroke of 8 feet. They are thoroughly steam-jacketed.

[1] See two papers by Mr. John G. Mair, before noticed, "On the Independent Testing of Steam Engines, and the Measurement of Heat used," and "The Results of some Independent Engine Tests," in the *Minutes of Proceedings of the Institution of Civil Engineers*, vol. lxx. page 313, and vol. lxxix. page 323.

Fig. 688.—J. Simpson & Co.: Woolf Compound Beam Condensing Pumping Steam Engine, Throckley Colliery. Scale 1/192d.

There are two steam boilers, having each two fire-grates 5 feet long, 2 feet 10 inches wide. The joint grate-area is 58¾ square feet, which was used in the 3d test. It was reduced by brickwork to 47 square feet in the 1st and 2d tests.

The service-pumps are of the bucket-and-plunger type, with in addi-

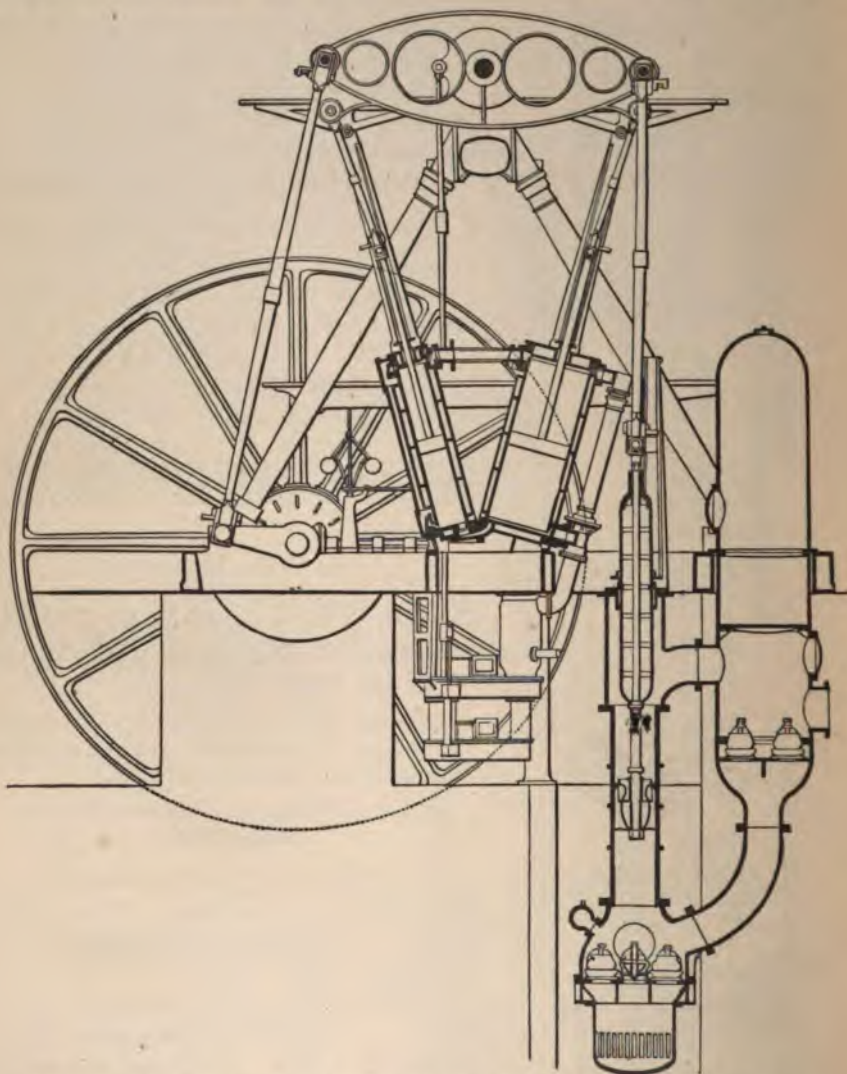Fig. 689.—E. D. Leavitt, Jun.: Beam Compound Rotative Condensing Pumping Steam Engine, for the Lawrence Water-works, U.S.A. Scale 1/132d.

tion a supplementary delivery-pipe, as shown in the figure. There are seven double-beat suction-valves, and four in the supplementary pipe, with the bucket-valve for the delivery. A small spherical chamber is attached to the lower valve-chamber, fitted with an air-cock at the top, by which

air may be admitted into the pump, which is found, at particular stages of water in the well, to conduce to ease in the working of the pump. The barrel of the pump is 26⅛ inches in diameter, the plunger is 18½ inches, with a stroke of 8 feet; and the plunger-rod is 4½ inches. The bottom and supplementary pump-valves are 15¾ inches in diameter outside the lower seat, 12½ inches inside the upper seat. The bucket-valve is 22 inches outside the lower seat, 15 inches inside. The air-vessel is 54 inches in diameter. The force-main is 30 inches in diameter, 4900 feet in length; the branches from the engines to the main are 24 inches in diameter, 75 feet long. The static lift is from 165 feet to 174 feet. The delivery is by an overflow from an upright pipe at the reservoir.

The conditions of the contract required that a duty of 95 million foot-pounds should be performed per 100 pounds of coal consumed; and that each engine should be capable of delivering 2 million gallons of water in 10 hours, with a speed of 16 revolutions, or 256 feet of piston per minute, and a working pressure in the boiler of 90 lbs. per square inch. The mean results of two trials show a duty of 96,186,979 foot-pounds per 100 pounds of coal, with a lift of 175.27 feet. The delivery into the reservoir was from 94.3 per cent to 95.2 per cent of the measured capacity of the pump. The coal was consumed at the rate of 330.3 pounds to 541.5 pounds per hour, or from 7.03 pounds to 9.22 pounds per square foot of grate-area per hour.

Weight of Moving Parts.	Tons.
Fly-wheel, 30 feet in diameter,	16
Beam, 16½ feet long, with pins and counterbalance,	11.50
1st piston and connections,	1.15
2d do. do.	1.86
Air-pump, piston, and connections,	.80
Plunger and bucket of service-pump,	3.21
Main connections, beam to crank,	1.70
Total,	36.22

CHAPTER XXXVII.—ROTATIVE BEAM CONDENSING PUMPING STEAM ENGINES.

CONSTRUCTED BY MESSRS. JAMES WATT & CO. FOR THE METROPOLITAN MAIN DRAINAGE WORKS, CROSSNESS.

(Cylinder 48 inches in diameter; stroke 9 feet.)

The Southern Outfall Sewer, for the drainage of the southern districts of London, discharges in the Thames, at Crossness Point, about four miles below Woolwich. The sewer is at a low level, its bottom being at a level 8 feet below the mean low water level, and the sewage is lifted by pumping into a covered reservoir at a level sufficiently high for discharging it into the river soon after high water. The reservoir is 560 feet long, 520 feet wide, the average height to the crown of the arches is 17 feet, and the
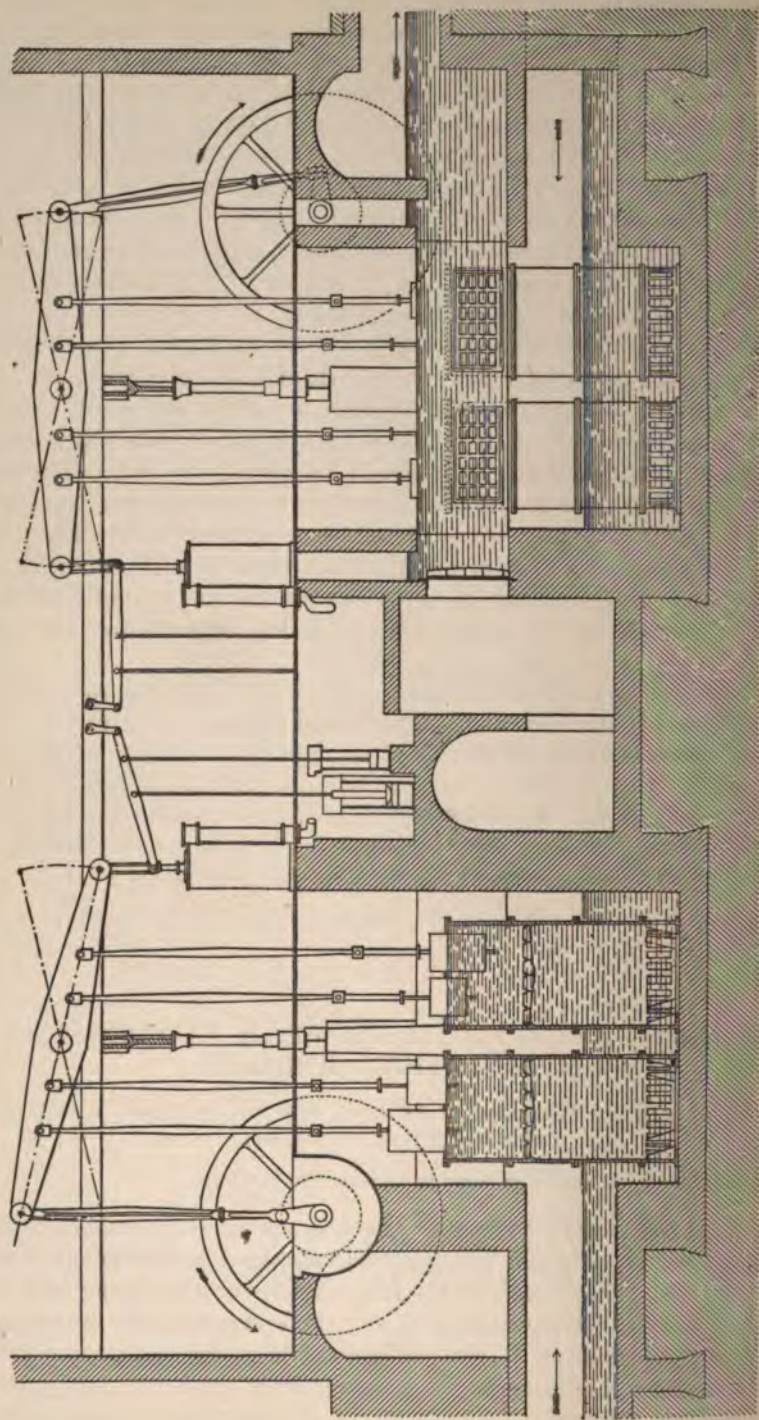
Fig. 690.—James Watt & Co.: Rotative Beam Condensing Pumping Steam Engines, Metropolitan Board of Works, Crossness Station. Scale 1/asgoth.

reservoir contains 24 million gallons when filled to a depth of 15 feet, the level of the overflow weirs.

The engines, fig. 690, have already been noticed, as steam engines simply, vol. i. page 506. There are four independent pumping engines, duplicates. Each engine works two sets of pumps, and each set consists of four single-acting plungers 4½ feet in diameter, working in a cylindrical casing 11½ feet in diameter. They are driven off both halves of the beam, two on one side, two on the other, at radii of 10 feet and 5 feet from the main centre. The two outer plungers in each set have a stroke of 4½ feet, and the two inner plungers have 2¼ feet of stroke. The plungers are hollow cylinders working through stuffing-boxes. Each plunger-pole is made with a long socket-joint piece for uncoupling the plunger when not required in action, by simply withdrawing the cotter: the socket being sufficiently long to allow of sliding the whole length of the stroke without disengaging from the plunger-pole. The suction-valves consist of a set of leather flaps loaded with wrought-iron plates, and fixed upon a horizontal frame having openings 9 inches by 18 inches. The rise of the flaps is limited by a crossbar fixed over each line of flaps. The delivery-valves are sets of vertical leather flaps similar to the suction-valves, having openings 12 inches by 18 inches.

The four sets of pumps worked by two adjoining engines deliver into a covered wrought-iron trough, 11½ feet wide, 10 feet high, placed longitudinally between the two engines, and discharging at the outer end into the upper-level culvert leading to the reservoir. The troughs, of which there are two, side by side, are each closed at the inner end by a penstock; and they are fitted with an air-vessel for the purpose of easing the action of the pumps when the trough is full, and the pumps are working against a head greater than the height of the trough. The lowest lift of the pumps is 19 feet when beginning to fill the reservoir, and the highest lift is 33 feet when the reservoir is full. The average working lift is 26 feet.

The pumping engines are double-acting, rotative, having each a single 48-inch cylinder with a stroke of 9 feet, steam-jacketed, connected to one end of the beam, which is 40 feet long, whilst a 27-feet fly-wheel, of 50 tons weight, is connected with a crank to the other end. The beam is made double, or of two sides, which are united to each other. The valves, fig. 691, double-beat, are 7¼ inches and 8¾ inches in diameter—the steam-valves and exhaust-valves respectively; worked by a cam-shaft, figs. 692, having fixed cams for the exhaust, and a sliding cam for the steam-valves, for varying the cut-off. The exhaust-cams have a lift of 2¼ inches, holding the valve open till near the end of the return stroke. The steam-cam has a lift of 1⅞ inches, with three steps for different grades of cut-off, at 12 per cent, 18½ per cent, and 25 per cent of the stroke. Sample indicator diagrams are shown in page 507, vol. i. This cam slides on a feather, and is shifted longitudinally by means of a rod within the shaft, which is hollow, and a toothed sector on a vertical shaft, shifted by hand. The steam-valve is open ⅛ inch at the beginning of the stroke; and the exhaust-valve 1¹¹/₁₆ inches. The steam is condensed in a condenser 32 inches in diameter,

by injection of sewage water. The air-pump is 24 inches in diameter. The feed-pump has a 6-inch cast-iron plunger, having a 27-inch stroke; with an air-vessel 2 feet in diameter, 5½ feet high, and a 5-inch feed-pipe. The pipes of each pair of engines are joined to a 7-inch pipe, and the two 7-inch
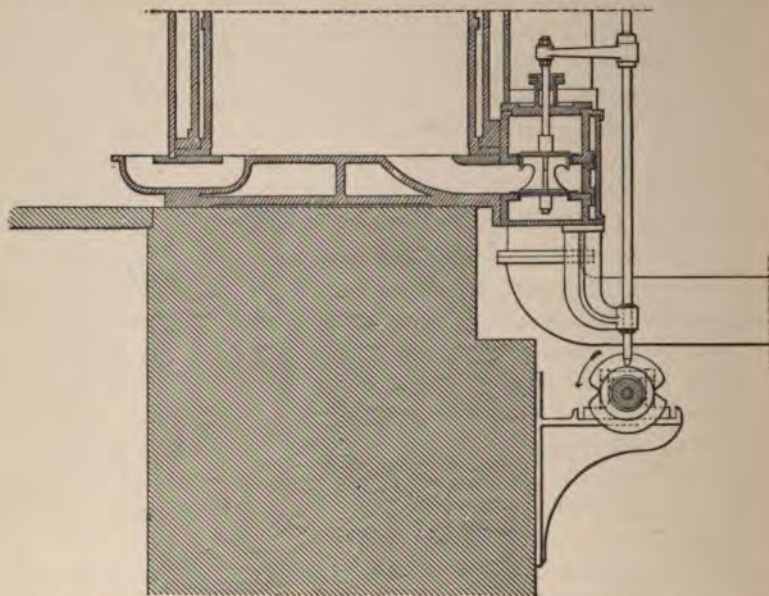

Fig. 691.—Crossness Pumping Engines: Double-beat Steam-valves and Cam-motion. Scale 1/36th.

pipes are joined to a 9½-inch pipe. The pumps are worked off the piston-rod by a counter beam.

The working steam pressure in the boilers is 35 lbs. per square inch, and steam is cut off in ordinary working at 18½ per cent, when the lift does not exceed 20 feet. Up to 34 feet of lift steam is admitted up to 25 per cent of the stroke. The working speed is 11 revolutions, or 198 feet of piston,
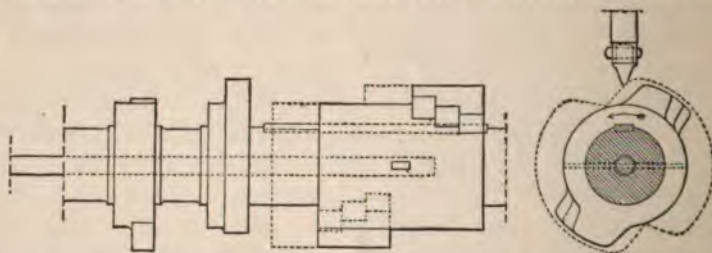
Figs. 692.—Crossness Pumping Engines: Cam-motion for Steam-valves. Scale 1/18th.

per minute. The usual effective mean pressure on the pistons is 18.6 lbs. per square inch, giving 202 indicator horse-power for each engine, and con-suming 2.2 pounds of coal per indicator horse-power per hour.

Steam was originally provided from twelve Cornish boilers, 6 feet in diameter, 30 feet long, with a furnace-tube 3¼ feet in diameter, reduced to

2 feet 11 inches in the flue portion. They were set in two ranges, each boiler upon two longitudinal walls, with a bottom flue and side return flues. The main steam-pipe for each range is 18 inches in diameter, with 12-inch branch pipes to each pair of cylinders. Five additional boilers, Lancashire, 7 feet by 30 feet, were added in 1875-6.

The duty is 86 millions of foot-pounds per 112 pounds of coal.

CHAP. XXXVIII.—HORIZONTAL COMPOUND CONDENSING DIFFERENTIAL PUMPING STEAM ENGINE.

DESIGNED AND CONSTRUCTED BY MESSRS. HATHORN, DAVEY, & CO., LEEDS, FOR THE STAFFORDSHIRE POTTERIES WATER-WORKS.

(Cylinders 24 inches and 48 inches in diameter; stroke 8 feet.)

This pumping engine, illustrated by fig. 694, is the type of differential engine usually employed for mining purposes; frequently also for water-works. This engine is one of a pair of engines erected at the Staffordshire Potteries Water-works, working under conditions similar to those of the St. Helen's pumping engine, already noticed.

The cylinders are in tandem: on a single cast-iron bed-plate, laid on a stone foundation, 13 feet deep. The motion is communicated to the pumps, which are vertical, by means of a pair of wrought-iron quadrants, or right-angled levers, on the top of the well, outside the engine-room;—the connecting-rod passing through an opening in the end wall of the engine-house.

The first and second cylinders, fig. 693, are 24 inches and 48 inches in diameter, with a stroke of 8 feet, having areas as 1 to 4. They are
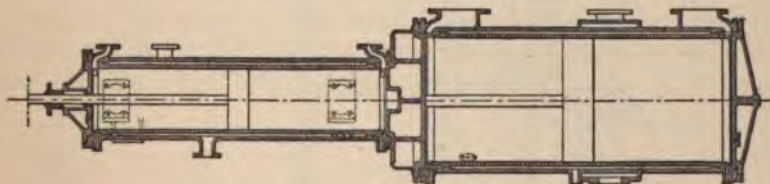

Fig. 693.—Davey's Horizontal Pumping Engine : Cylinders, Section.   Scale 1/72d.

thoroughly steam-jacketed. The pumps consist of two plunger-pumps, each 13 inches in diameter, of 8-feet stroke; and two bucket-pumps, each 14 inches in diameter, of 8-feet stroke. The well is 100 feet deep; and the water is lifted by the bucket-pumps from the bottom into a cistern placed at the level of the plunger-pumps. By these the water is forced through an air-vessel into the rising main to a level 425 feet above the top of the well.

The motion for the valve-gear is taken from the shaft of the near quadrant, by an arm keyed on the shaft; from which through a connecting-
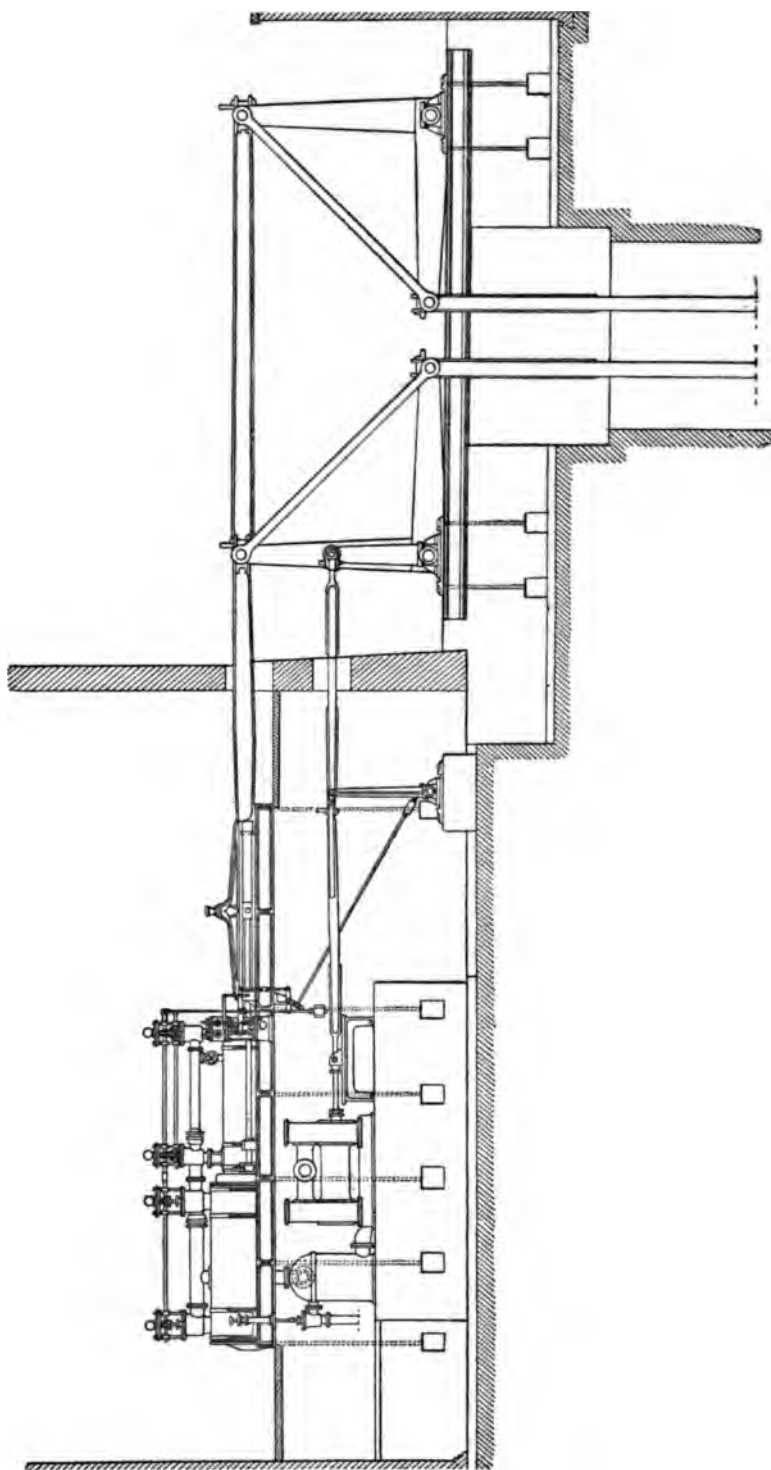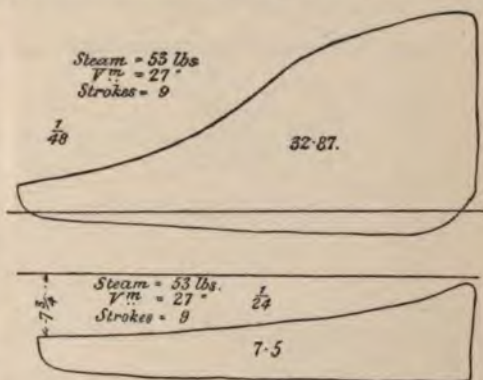
Fig. 694.—Davey's Compound Differential Pumping Engine for the Staffordshire Potteries Water-works. Constructed by Messrs. Hathorn, Davey, & Co., Leeds. Scale 1/144th.

bar reciprocating motion is communicated to an intermediate rocking arm. From a short arm on the pivot of this lever, a connection is made to the valve-gear. A direct connection, also, is made from this arm to work the air-pump, with a stroke of 4 feet, or half the stroke of the steam cylinders. The condenser is an ordinary injection-condenser, taking water from a cooling pond.

The normal speed of the engine is at the rate of 10 double-strokes, or 160 feet of piston, per minute. The engine is capable of making from 12 to 14 double-strokes, or 192 to 224 feet of piston, per minute.

The indicator diagrams, figs. 695, were taken from the two cylinders of this engine, making 9 double-strokes per minute, in ordinary working. With a pressure of 53 lbs. per square inch above the atmosphere in the boiler, the initial pressure in the cylinder is 50 lbs. The pressure is reduced by wiredrawing to 37 lbs. at the end of the admission, which is 40 per cent of the stroke; and is expanded continuously in the second cylinder to a pressure of 7¾ lbs. below the atmospheric line. The nominal ratio of expansion is 10. The vacuum line

Figs. 695.—Davey's Pumping Engine: Staffordshire Potteries Water-works. Indicator Diagrams.

is 13.4 lbs. below the atmospheric line, almost identical with the vacuum in the condenser, which is 27 inches of mercury.

For these indicator results, the pistons were moving at an average speed of 144 feet per minute; and the consumption of steam was at the rate of 17 pounds per horse-power. It seems clear that expansive working with high pressures in the boiler, can be carried to as great an extent as is desirable in the differential pumping engine.

CHAPTER XXXIX.—OTHER HORIZONTAL ROTATIVE PUMPING ENGINES.

### HORIZONTAL COMPOUND RECEIVER ENGINE, BARROW HILL, WEST MIDDLESEX WATER-WORKS.

CONSTRUCTED BY MESSRS. JAMES SIMPSON & CO., LONDON.

(Cylinders 21½ inches and 35 inches in diameter; strokes 3½ feet.)

A horizontal compound receiver condensing pumping engine was erected at Barrow Hill Pumping Station, and started early in 1886. The first and second cylinders are connected to cranks at right angles on the

fly-wheel shaft. The pumps are two in number, double-acting, with four valves; placed behind the cylinders, and connected direct to and worked by prolongations of the piston-rods, one for each cylinder. The first cylinder is 21½ inches in diameter, and the second cylinder is 35 inches, in the ratio of 1 to 2.07. The pump-pistons are 12½ inches in diameter. The stroke of all the pistons is 3½ feet long. Both of the cylinders are completely steam-jacketed with steam direct from the boiler, supplied independently of the working steam for the cylinders. The steam condensed in the jackets gravitates back to the boilers. The steam is exhausted from the first cylinder into a steam-jacketed reservoir overhead, whence it passes to the second cylinder. The distribution of the working steam is effected by means of a slide-valve with a cut-off plate or expansion valve on the back, for each cylinder. There are three Cornish boilers, each 5½ feet in diameter, 20 feet long. In this instance only one main valve is applied to each cylinder, and not two as in beam engines constructed by Messrs. Simpson & Co. It was considered that for so short a stroke, comparatively, in the
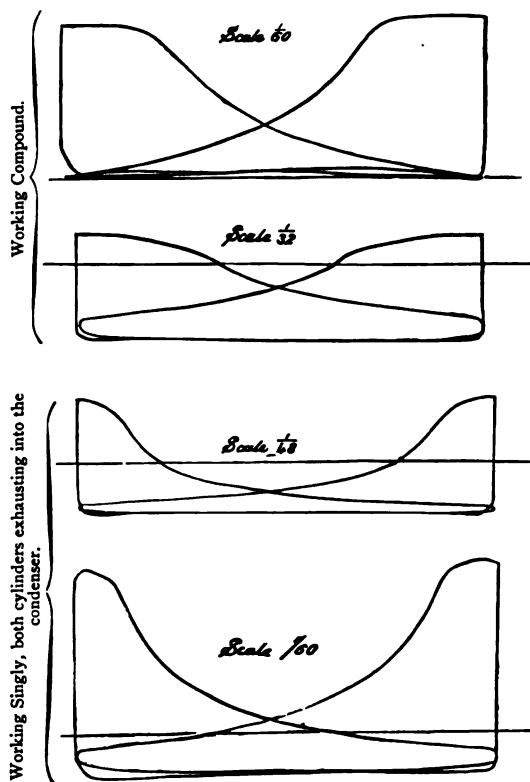
Figs. 696.—Compound Pumping Engine, Barrow Hill.
Sample Indicator Diagrams.

Barrow Hill engine, the distribution of steam could be effected without an excessive volume of clearance space.

The engine is arranged so that either cylinder can be worked independently. The indicator diagrams, figs. 696, show a very even distribution of power between the two cylinders when working compound. The lower diagrams were taken from the cylinders when working independently, the first cylinder, with the second, exhausting into the condenser.

The average results of an official trial for 24 hours, conducted by Mr. Thomas Hack, with this engine, in July, 1886, show excellent performance, notwithstanding the drawback of a much lower head and lower speed than the engine was constructed for, due to the requirements of the district. Steam of 61 lbs. working pressure per square inch was supplied

from two boilers, using Nixon's Navigation coal. The engines made
21½ revolutions per minute; the average head on the pump was 141.3 feet;
the barometer was 29.9 inches; the vacuum 27.4 inches. The power
indicated was 75.7 horse-power; the effective power in water lifted was
65.75 horse-power, or 86.6 per cent of the indicator power; 1.81 pounds of
coal were consumed per indicator horse-power, or 2.09 pounds per effective
horse-power. The duty was 105.93 millions per 112 pounds of coal, against
the contract duty, 88.7 millions. The feed-water used per indicator horse-
power per hour was 15.3 pounds.

An engine of this character may be taken as of the best type of a
rotative pumping engine; the foundations required are much lighter than
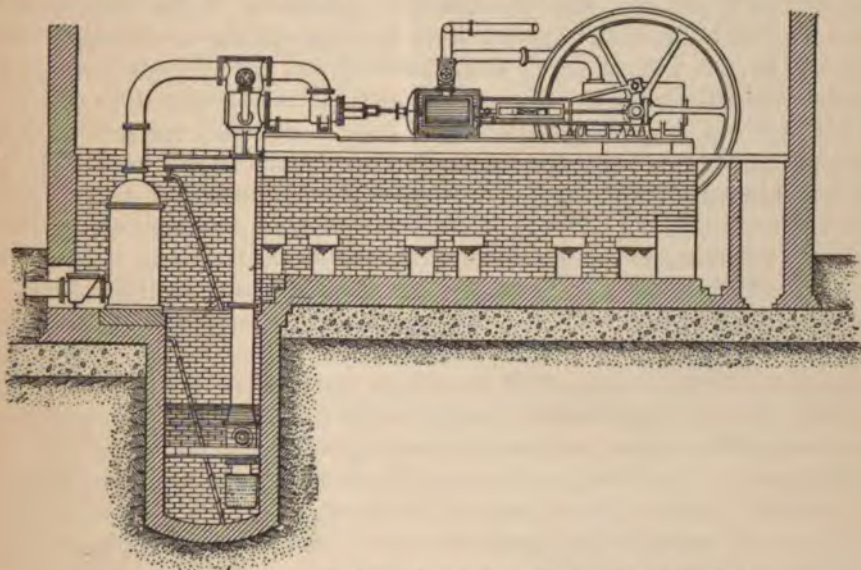

Fig. 697.—J. Simpson & Co.: Horizontal Pumping Steam Engine, Haggar Lane Station,
East London Water-works. Scale 1/144th.

what are necessary for a beam engine of equal power; the load on the
foundation is more equally distributed, and the first cost is much less.
When the floor of the engine-house is not placed higher than from 14 feet
to 16 feet above the lowest water-line, a horizontal engine, driving the
pumps directly by prolongations of the piston-rods, is preferable to a
beam rotative engine.

HORIZONTAL CONDENSING PUMPING STEAM ENGINE.

CONSTRUCTED BY MESSRS. JAMES SIMPSON & CO. FOR HAGGAR LANE STATION,
EAST LONDON WATER-WORKS.

(Cylinders 24 inches in diameter; strokes 3 feet.)

A pair of independent horizontal direct-acting pumping engines, fig.
697, were erected at Haggar Lane Station. Each cylinder is 24 inches in
diameter, with a stroke of 3 feet. The piston-rod passes through each end

of the cylinder, connected to the crank and fly-wheel at one end, and to a piston-and-plunger pump at the other end.

HORIZONTAL PUMPING STEAM ENGINE.

DESIGNED AND CONSTRUCTED BY MESSRS. FARCOT & SONS, PARIS, FOR THE PARIS WATER-WORKS, ST. MAUR.[1]

The engine and the pump are horizontal, on one piston-rod, with a fly-wheel movement at one end. The principal characteristic is the form of the pumps and plunger. There are two pumps, in line, worked by one plunger, which reciprocates between them. The body of each pump is considerably larger in diameter than the plunger, and of elliptical section longitudinally, so that the greatest enlargement is at the middle of its length. The water thus held in reserve flows in laterally to occupy the void created by the plunger, at a comparatively low velocity and with comparative facility, in regard to the movement of water required to follow up the plunger, of an ordinary close-fitting pump. A higher speed of piston is thus permissible for working without shocks. To afford still greater facility of movement, the ends of the double-ended plunger, instead of being square, are tapered conically; or, still better, formed with a wave-line taper, which is better either for piercing the body of water in the pump for the instroke, or for retiring through it for the outstroke. With such facilities for rapid motion, the regular speed of the pump and engine amounts to thirty double-strokes, about 6 feet long, or 354 feet of piston and plunger per minute. The total length of the pieces in reciprocation is more than 65 feet; the volume of water lifted amounts to from 360 to 380 cubic feet, or about 2300 gallons per minute, under a pressure of from eight to ten atmospheres. The pump-valves are hinged, and their action is adjusted by means of india-rubber springs of tubular form, the pressure of which is regulated by means of set-screws and nuts. An air-vessel is placed above each set of delivery-valves.

The engine is of the Corliss type, and the valves are so closely adjusted that the total clearance at each end of the cylinder is less than 1 per cent. The cylinder is steam-jacketed. The fuel consumed varies from 1.984 pounds to 2.095 pounds per horse-power of duty in water lifted: corresponding to 1.764 pounds per horse-power at the main shaft, and to 1.543 pounds per indicator horse-power. These are the results of performances officially reported.

HORIZONTAL COMPOUND PUMPING STEAM ENGINE.

CONSTRUCTED BY THE ALSATIAN SOCIETY FOR MULHOUSE WATER-WORKS.[2]

(Cylinders 18.7 inches and 26.7 inches in diameter; stroke 39.37 inches.)

The pumping steam engines of the low-service water-works of Mulhouse, figs. 698 and 699, were constructed by the *Société Alsacienne de Constructions*

[1] *Annales Industrielles*, April, May, 1878.

[2] See the *Bulletin de la Société Industrielle de Mulhouse*, 1885, page 561; and 1886, page 133, from which the materials for this notice are derived.

Mécaniques, Mulhouse, for the Hirzbach pumping station. They consist of two groups of horizontal compound steam engines, connected direct by the piston-rods to four horizontal double-action pumps, with plungers. They were required to consume at most 10 kilogrammes of steam per *cheval* per hour, or 22.35 pounds per horse-power per hour. The boilers are of the ordinary French type, fitted with Green's economizers. The power required to raise 17,000 cubic metres—the estimated supply—is 225 horse-power; but only two engines of 75 horse-power each have as yet been erected, with three boilers. The two cylinders of each engine are connected to cranks at right angles on the fly-wheel shaft. Each cylinder is placed on a stiff bed-frame, on separate foundations. They are each thoroughly steam-jacketed, cast in one piece with the jacket; and the exhaust-steam from the first cylinder passes into and through an intermediate receiver, placed low, between the foundations, before passing to the second cylinder. This receiver is a vertical cylinder, steam-jacketed, heated by steam direct from the boiler. The condensed steam from all the jackets is collected at the reservoir and is drawn off through a single tap. The condensation-water escapes below the level of the boilers, to waste. The steam exhausted from the second cylinder passes to the condenser, which is vertical, and placed under the ground-level near the fly-wheel shaft; the air-pump is placed under the fly-wheel shaft, and is worked by a crank off the shaft.

The cylinders are 18.7 inches and 26.6 inches in diameter, having the area-ratio of 1 to 2; with a stroke of 1 metre, or 39.37 inches. The normal speed is 27 turns, or 177 feet of pistons, per minute. The air-pump is 19¼ inches in diameter, and has a stroke of 19⅝ inches.

The pistons are of the Mather-Platt system. The crossheads are of wrought iron, working between four lateral guide-bars. The connecting-rods are 4½ times the length of the crank. The fly-wheel, placed on the middle of the shaft, is 15¾ feet in diameter, and weighs 7 tons. The journals are 6¾ inches in diameter, in gun-metal bearings, in four parts, with means of lateral adjustment.

The distribution is effected by means of four flat valves to each cylinder: two for admission, on the top of the cylinder; two for exhaust, on the side: easily accessible. These valves are moved by two eccentrics on the fly-wheel shaft; one for admission, keyed on the shaft at 60° of advance, cutting-off up to 70 per cent, and working trip-gear on the top of the cylinder. The cut-off valve is regulated by the governor for the first cylinder; by hand for the second cylinder, so that the intermediate drop of pressure may be minimized. The exhaust eccentrics are fixed in such a manner as to produce considerable compression of steam in the cylinder in closing the exhaust.

The double-acting service-pumps, one to each cylinder, are connected by prolongations of the piston-rods. Each plunger works into two pump-casings or bodies in alignment, tied to each other, and bolted to the bed-frame. The stuffing-boxes are made double, with a hydraulic joint, supplied with water under pressure from the delivery-valve chambers, in
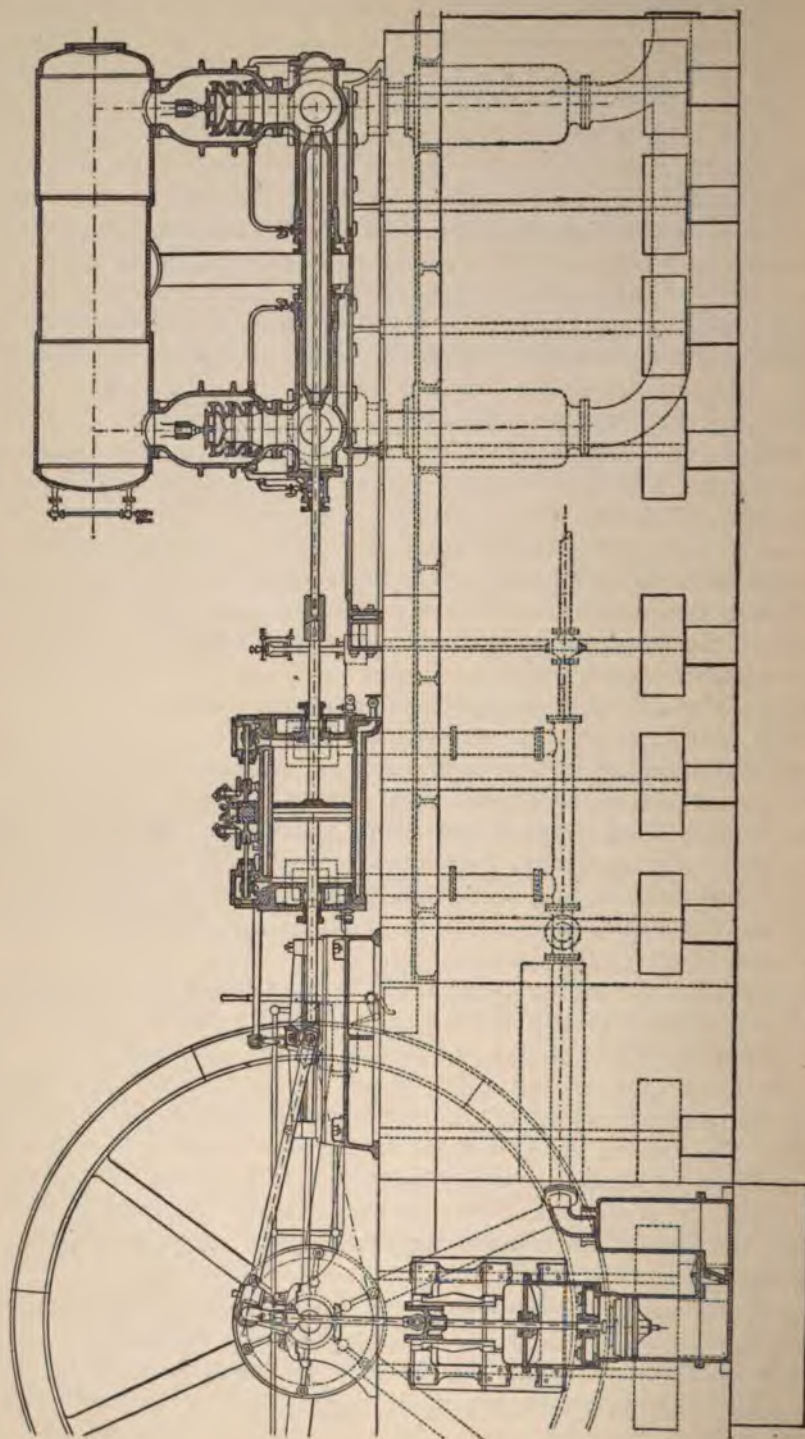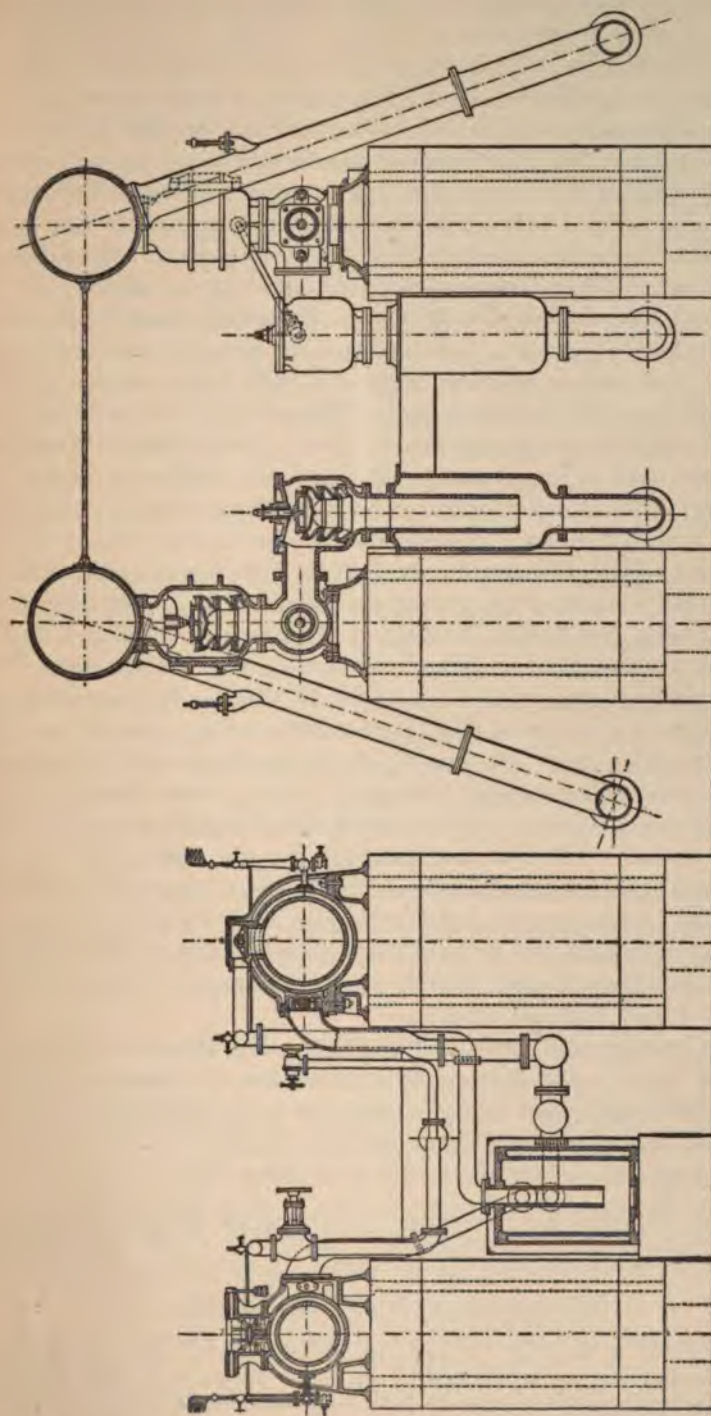
✱ Fig. 698.—Alsatian Society: Horizontal Compound Pumping Steam Engine, Hirtzbach Pumping Station.   Longitudinal Section.   Scale 1/60th.

Cross Section at Pumps.

Cross Section through Cylinder and Reheater.

Figs. 699. — Alsatian Society: Horizontal Compound Pumping Steam Engine, Hirzbach Pumping Station. Scale 1/6oth.

order to obviate the entrance of air.   The plunger is $9\frac{1}{4}$ inches in diameter, with 39.37 inches of stroke—the same as that of the pistons.   The suction-valve chambers are placed at one side of the pump-bodies, and the delivery-valve chambers above them.   An air-vessel is adapted concentrically under each suction-valve, having seven times the volume of one stroke of the pump.   The suction-pipes are 10 inches in diameter, and they branch from a single $13\frac{3}{4}$-inch pipe through which the water comes from the wells.   The normal velocity of the water in the pipes is 132 feet per minute.   Each valve consists of three horizontal cast-iron rings faced with leather, resting on three seats, superposed, united by a central bolt.   The lift is limited to $5/_{16}$ inch, and with this lift the united area of passage-way through the valves is greater than that of the pipes.   Above the delivery-valves there are the large air-vessels, of plate-iron, having a volume 48 times the capacity of one stroke of the pump.   The neckings of the reservoirs are of wrought iron, riveted to them.   Each of these is fitted with a glass-gauge and a manometer, graduated for metres of water.   The delivery-pipes from the reservoirs are 10 inches in diameter, and they discharge into the 20-inch main underground.

The steam boilers, three in number, are $47\frac{1}{4}$ inches in diameter, 23 feet long, with three heaters $21\frac{1}{2}$ inches in diameter, $26\frac{1}{4}$ feet long.   Each boiler has 494 square feet of heating surface, and is stamped for a total pressure of $6\frac{1}{2}$ atmospheres.   The Green economizer has 120 pipes.

These pumping engines were tested by M. Walther-Meunier in August, 1885, with a total pressure of $6\frac{1}{2}$ atmospheres, or about 97 lbs. per square inch; 27.42 revolutions, or 180 feet of piston per minute were made, making 65.1 indicator horse-power, and consuming 16.38 pounds of water as steam per horse-power per hour, which includes the condensation-water from the steam-jackets.   The water delivered by the pumps per minute, 1,001,220 gallons, was raised to a height of 183.44 feet, developing 55.64 effective horse-power of useful work done; and for which 19.20 pounds of steam was consumed per horse-power.   The effective work was 85.3 per cent of the indicator power.   The pumps delivered from 98 per cent to 97 per cent of their working capacity.

In a preliminary trial, indicator diagrams were taken from the pumps at the same time as those from the engine; and the results showed the efficiency of the engine 89.6 per cent, and that of the pumps 95.2 per cent.

The pumps have been worked at the rate of 36 revolutions, or 236 feet of piston per minute, with a lift of 18 feet, without shock.

PAIR OF HORIZONTAL PUMPING CONDENSING STEAM ENGINES.

CONSTRUCTED BY MESSRS. BURGHARDT BROTHERS, FOR THE COLMAR WATER-WORKS.[1]

(Cylinders 17.7 inches in diameter; stroke $31\frac{1}{2}$ inches.)

Two horizontal engines, with single cylinders, are directly connected

[1] See an illustrated paper on Colmar Water-works, in the *Bulletin de la Société Industrielle de Mulhouse*, 1885; page 130; and an abstract of the paper in the *Proceedings of the Institution of Civil Engineers*, vol. lxxx. page 413.

by a prolongation of the piston-rods to join the pump-rods in alignment. They are connected to one fly-wheel shaft. The steam cylinders are 17.7 inches in diameter, steam-jacketed, with a stroke of 31½ inches, making from 15 to 35 revolutions per minute against a total calculated head of 187½ feet of water. The normal speed is 30 turns per minute. Collmann's valve-gear is applied, having equilibrium-valves capable of cutting off at from 0 to 65 per cent of the stroke. A high-speed governor is employed, by a special adaptation of which the speed may be varied according to the demand for water. The plummer-blocks for the fly-wheel shaft are in four pieces, with bronze bearings adjustable laterally. The fly-wheel is 13 feet in diameter, and weighs 6 tons. It is sufficient to ensure uniformity of motion even for high degrees of expansion, and whilst one engine only is at work. The air-pumps are constructed with plungers.

There are two 10-inch service-pumps, side by side, horizontal, double-acting, with plunger-pistons, which, it is considered, if well made, though expensive at first, possess the greatest efficiency of delivery. The pistons are not packed, and they depend for tightness on accuracy of fit. Their dimensions were calculated for a coefficient of delivery of .90. The suction-pipes are 10¾ inches in diameter, to suit a velocity of flow of about 120 feet per minute; the discharge pipe for the two pumps is 8¾ inches in diameter, giving a velocity of flow of 180 feet per minute. The main delivery-pipe conducting the water to the reservoir, at a distance of 3280 yards, is 13¾ inches in diameter. The pump-valves are on the Thornstzec system, cylindrical, in four stages, giving a wide combined thoroughfare, with very little lift, only ⅓ inch. The seats and valves are of cast iron, the valves being faced with india-rubber. The uppermost valve is 6 inches in diameter, 12 inches outside; the remaining three valves are 10¾ inches inside, 16¾ inches outside.

Steam is supplied from two boilers of the usual French type, only one working, the other in reserve; having each 18 square feet of grate-area, 425 feet of heating surface, with, in addition, 516 square feet of feed-water heating surface in forty-eight pipes. The absolute pressure is 6½ atmospheres.

From the results of a trial lasting 6 hours 24 minutes, it appears that the pumps delivered, at each stroke, a volume of water 98 per cent of their working capacity. The total lift was 187¾ feet, representing 60½ effective horse-power; whilst the indicator power of the engines was 78½ horse-power, showing an effective work 77 per cent of the engine power. Allowing 90 per cent of efficiency of the engine itself, the efficiency of the pump in itself would be 85 per cent. Steam was consumed at the rate of 19 pounds per indicator horse-power.

HORIZONTAL PUMPING MACHINERY.

CONSTRUCTED BY MESSRS. BOSISIO, LARINI, NATHAN, & CO., MILAN.

This pumping machinery, on a system much employed in Continental water-works, consists of two horizontal double-acting pumps, or two pairs

of single-acting pumps, laid in parallel lines, connected to one transverse shaft, driven by a steam engine, of which the speed is reduced by means of spur-gear. The four single pumps deliver to a central reservoir and air-vessel, from which the water passes into the main.[1]

The rams are 23.62 inches in diameter, with a stroke of 39.4 inches. They are of cast iron, hollow, of such a thickness that their specific gravity is equal to that of the water by which they are surrounded. By this adjustment the weight of the rams is water-borne, and all unequal wear is taken off the glands. The large stuffing-boxes through which the rams work are completely submerged in two small tanks, one for each pair of barrels. Thus, by the aid of the water-seal, the packing may be kept loose, and frictional resistance minimized. The passages through the india-rubber disc-valves of the pumps, of which there are seven inlet and seven outlet valves, are made very ample; the lift of the valves, which are of india-rubber, is minimized, and the covers of the delivery valves are formed as air-vessels. Thus, shocks are obviated, and the pumps work in silence. Special air-discharge valves are provided for starting; and safety-valves to be lifted for the purpose of throwing any single barrel out of action without stopping. The charge of air in the air-vessel is maintained constant by means of a copper float in the vessel acting on a special three-way cock connected with small air-valves on the pump-barrels: causing a fresh supply of air to be introduced into, or an excess to be discharged from, the air-vessel as occasion requires.

The pumps are connected to cranks on the ends of a shaft, carrying a spur-wheel 16½ feet in diameter, driven by a pinion of 3¾ feet in diameter, on the main shaft of the engine.

The system of pumps was designed to deliver 1000 tons of water per hour under a head of 200 feet. From the results of trials, it appears that the effective work was not less than 85 per cent of the engine-power; and the loss of volume delivered was not more than 5 per cent of the working capacity of the pumps, whilst the average was less than 2 per cent.

HORIZONTAL COMPOUND CONDENSING ACCUMULATOR PUMPING STEAM ENGINE.

CONSTRUCTED BY MR. BENJAMIN WALKER, LEEDS.

(Cylinders 30 inches and 50 inches in diameter; stroke 30 inches.)

The use of pressure by the medium of water—water pressure, as it is called—is extensive; and it demands the production and use of water-pressure economically. Mr. Walker concludes from his experience that fairly high steam-boiler pressures, say from 80 lbs. to 90 lbs. per square inch, should be practised; that the most advantageous hydraulic pressure is from 600 lbs. to 750 lbs. per square inch; that the engines for pressing the water should be compound, highly expansive, and fitted with surface

[1] See a notice of these pumps in *Engineering*, March 6 and 20, 1885, pages 237, 286; on which the above description and illustrations are based.

condensers. Large accumulators also are necessary; and, if possible, the engines should be kept going continuously. They are much more economical when driven at from 150 to 180 feet per minute than at a lower speed. The valves and waterways, especially those of the inlet, should be large, the lift being small. Cup-leathers and all packing which is not easily accessible, and where leakage cannot at once be detected, should be avoided, rams being always preferable to buckets.[1] Mr. Walker prefers compound to simple steam engines for pumping against high pressures. A compound engine of about 300 indicator horse-power is illustrated by
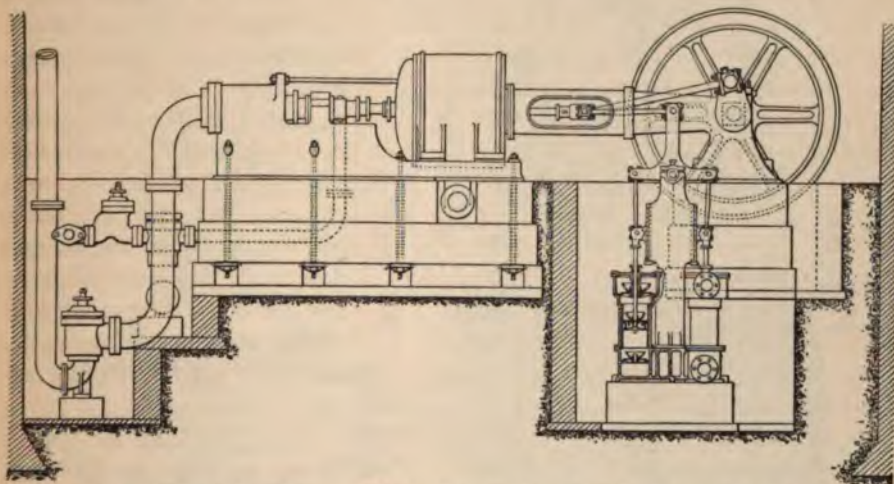
Fig. 700.—B. Walker: Horizontal Compound Condensing Accumulator Pumping Steam Engine. Scale 1/108th.

fig. 700, in which the first cylinder is 30 inches and the second cylinder 50 inches in diameter, with 30 inches of stroke. The cylinders are thoroughly steam-jacketed. Two double-acting pumps are worked direct by connection with the piston-rods, one to each rod; and the rods are prolonged through the other ends of the cylinders, and connected to two cranks at right angles on the ends of the fly-wheel shaft. Each pump-ram is of two diameters, 9 inches and 6½ inches, the smaller section having half the sectional area of the larger. The action of the pump is similar to that of the ordinary bucket-and-plunger pump, producing a continuous flow, except that, instead of a liner and cup-leathers, ordinary packing is available. This kind of pump, it is stated, has given great satisfaction; there is not practically any leakage. The engine is fitted with a surface-condenser, air-pump, circulating pump, and boiler feed-pump. By the circulating pump the water is sent through the condenser-tubes to the tank overhead for the supply of the feed-pumps. Mr. Walker states that compound engines of this class have proved to be more economical in working than simple engines.

[1] See a paper on "Machinery for Steel Making by the Bessemer and the Siemens Processes," in the *Proceedings of the Institution of Civil Engineers*, vol. lxiii. 1880–81; page 2.

CHAPTER XL.—THE WORTHINGTON STEAM PUMP.

CONSTRUCTED BY THE WORTHINGTON PUMPING ENGINE COMPANY, LONDON.

The Worthington Pump of 1844, is said to be the first of that class of direct-acting non-rotative pumps, of which the steam-valves were controlled by mechanism which had no positive mechanical connection between the
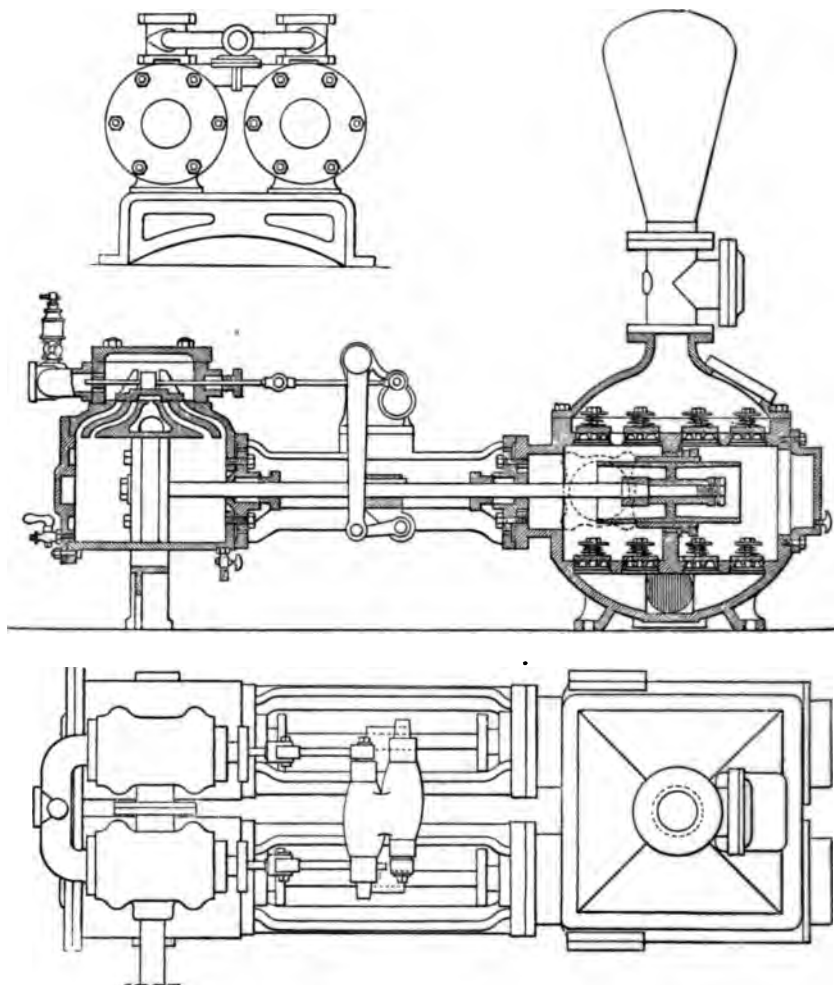
Figs. 701.—Worthington Pump.　Scale 1/16th.

movements of the piston and the steam-valve.　The Worthington pump of 1849 was a single-cylinder pump, said to have been the first independent pump used on steam-ships for feeding boilers, and for other purposes.　It was replaced by the type of Worthington pump now in use.

The ordinary Worthington steam-pump consists of two steam-pumps,— each of which comprises a steam-cylinder and a pump,—placed side by

side. The two steam-cylinders and the two pumps are cast together; and the two castings are connected by distance-pieces. The pumps are so combined, as to act reciprocally on the steam-valves of each other. By the action of one piston, steam is given to the other, after which it finishes its own stroke, and waits for its valve to be acted on and shifted before it can renew its motion. During this short pause the water-valves fall to their seats quietly, harshness of motion is prevented, and there is a uniform delivery without pulsation or noise. As one or other of the steam-valves is open, there are no dead-points.

The pump illustrated by figs. 701 has a 9-inch steam-cylinder and a $5\frac{1}{4}$-inch pump-ram, with a stroke of 10 inches. The steam-piston and the pump-plunger are fixed to one rod, and so reciprocate in unison. The steam-cylinder is fitted with an ordinary slide-valve, the reciprocating motion of which is derived from a vibrating arm suspended between the cylinders, the lower end of which is linked to the piston-rod of the alternate cylinder, and receives the full swing of the stroke. Through a shorter arm on the shaft of the longer arm, the traverse is reduced and communicated
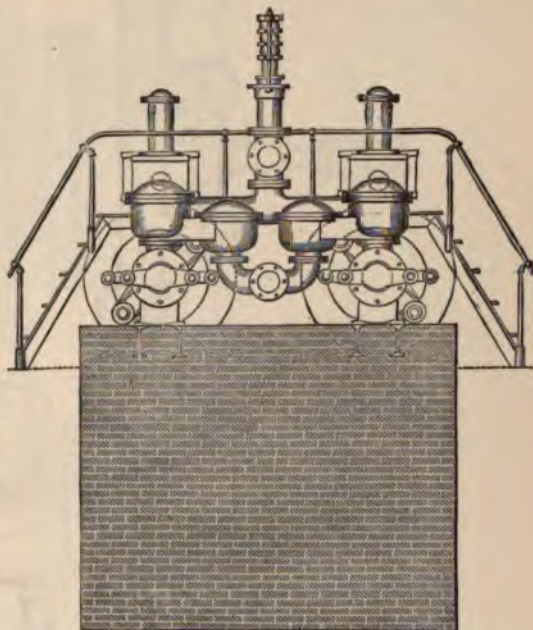

Fig. 702.—Worthington Compound Condensing High-pressure Pumping Steam Engine: End View.

to the valve. The double-acting plunger on the end of the piston-rod works through a partition, by which the pump-casing is divided into two compartments: the partition being fitted with a deep packing-ring accurately bored, neither elastic nor adjustable. But the ring on the plunger can be quickly removed, and either refitted or exchanged. The water enters the pump through a number of suction-valves, in each compartment alternately, below the plunger, and is discharged through delivery-valves in the top. The valves are india-rubber discs, 3 inches in diameter; they give ample waterway.

THE WORTHINGTON COMPOUND CONDENSING HIGH-PRESSURE PUMPING STEAM ENGINE.

A design of Worthington pump, for large services requiring the delivery of fluids against very high pressures, is shown in figs. 702, 703, and 704. The cylinders are like those of a Worthington waterworks engine. Plungers

with exterior packings are employed; two distinct plungers to each pump: one working in each end of a long barrel, divided by a partition midway. The two plungers are connected by crossheads and side-rods to the steam-piston rods; and alternately make their in-strokes and out-strokes, so that
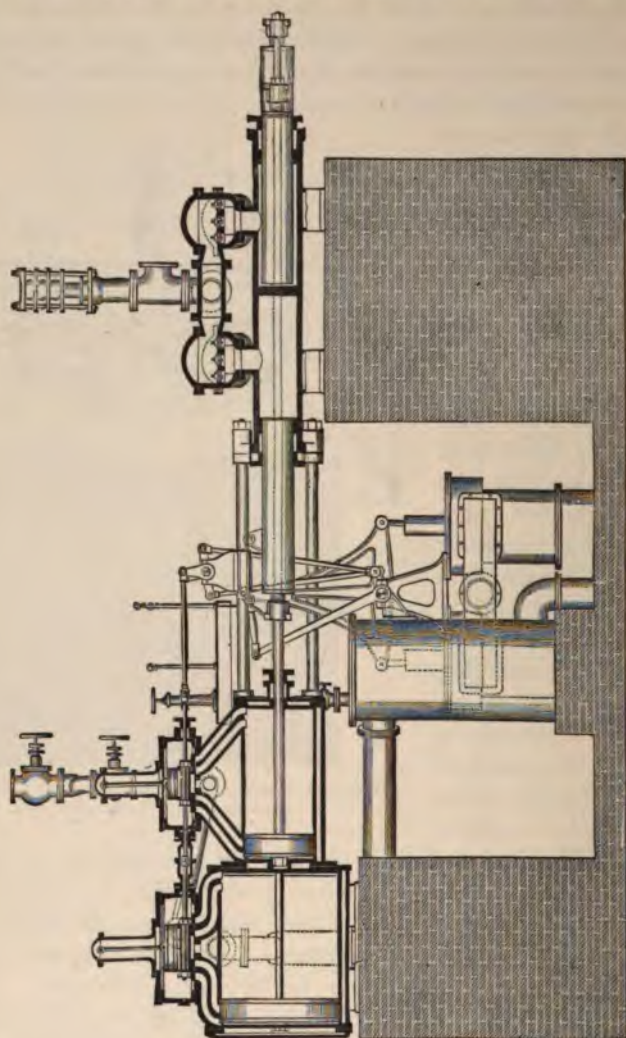

Fig. 703.—Worthington Compound Condensing High-pressure Pumping Steam Engine: Longitudinal Section.

while one is drawing, the other is forcing, and the pump works as a double-acting pump. The valves are metallic with leather faces.

These pumps work, in some cases, against a pressure of 4000 lbs. or so on the square inch. On the oil-pipe lines, a number of these engines, varying from 200 to 500 horse-power each, are in constant use: some of them being required to deliver from 15,000 to 25,000 barrels of oil per day against pressures varying from 1000 lbs. to 1500 lbs. per square inch.

Mr. John G. Mair gives the results of tests conducted by him, in

December, 1885, of a Worthington compound condensing pumping engine, working at Brooklyn, New York, illustrated by fig. 705.[1] The first cylinder was 17⅞ inches in diameter; the second cylinder 35⅞ fully; in the ratio 1 to 4. The pump-plungers were 17 5/16 inches in diameter; length of
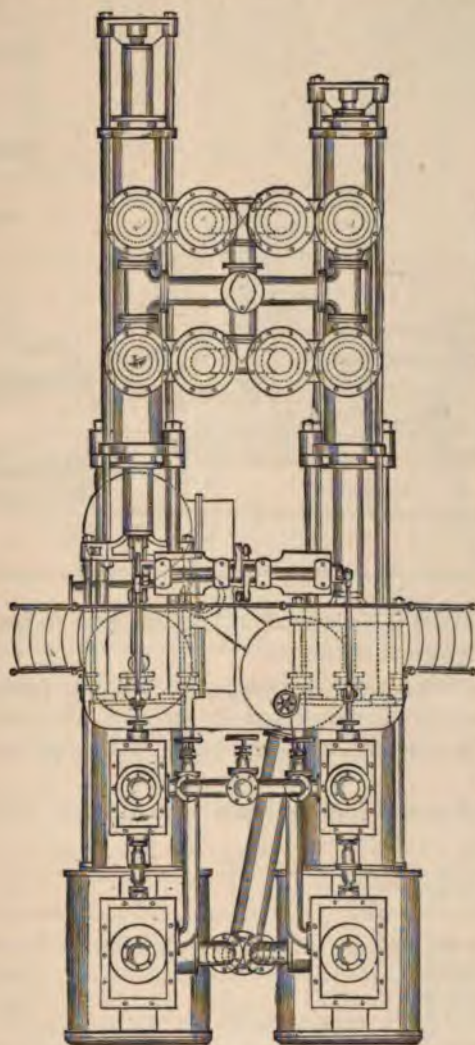

Fig. 704.—Worthington Compound Condensing High-pressure Pumping Steam Engine: Plan.

stroke, 26 inches. To obtain a perfectly uniform pressure on the pump-plungers, and a steady delivery of water, compensators are employed, for the purpose of equalizing the pressures in the cylinders with high rates of expansion. Two small cylinders are attached to the piston-rod, containing water or air under pressure. The excess of work, which is a maximum at

[1] See a paper on "Experiments on a Direct-acting Steam Pump," by John George Mair, in the *Proceedings of the Institution of Civil Engineers*, vol. lxxxvi. 1885–86; page 293.

the beginning of the stroke and decreases to nothing at half-stroke, is taken
up by those small cylinders. After half-stroke, when the steam-pressure is
less than the water-pressure, the work so taken up is given out, increasing
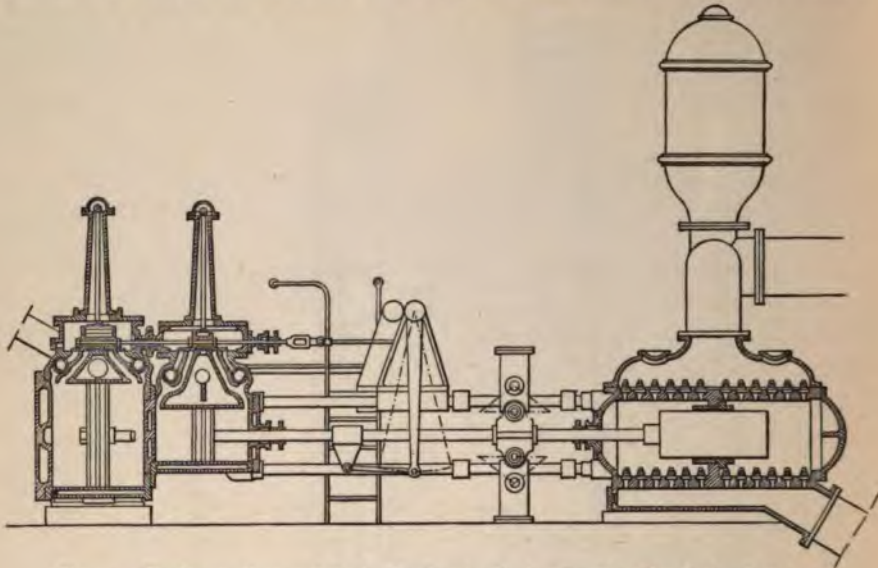towards the end of the stroke, in such a manner that the unequal action of

Fig. 705.—Worthington Compound Condensing Pumping Engine, Brooklyn, New York. Scale 1/64th.

the steam on the pistons is equalized in transmission to the plungers, and a
perfectly steady pressure is obtained.

The working steam, after leaving the engine, passed through the
eduction-pipe to an independent condenser and air-pump worked by a
separate engine; the condensed steam being delivered into the discharge
tank.

Results of three out of nine trials which were made are here ab-
stracted:—

No. of Trial	1.	2.	3.
Working pressure in the boiler	59.3 lbs.	80.4 lbs.	101.0 lbs.
Double-strokes per minute	45.0	39.26	40.10
Speed of piston in feet per minute	97.5 ft.	85.0 ft.	86.9 ft.
Feed-water per minute (tank measurement)	34.12 lbs.	30.33 lbs.	36.26 lbs.
Jacket drains per minute	4.22 ,,	4.15 ,,	4.57 ,,
Indicator horse-power	119.2 H.P.	108.1 H.P.	130.5 H.P.
Pump horse-power	109.3 ,,	97.9 ,,	120.4 ,,
Efficiency	91.7%	90.6%	92.3%
Feed per indicator horse-power, through cylin.	15.05 lbs.	14.53 lbs.	14.57 lbs.
Do. do. do. ,, jackets	2.12 ,,	2.30 ,,	2.10 ,,
Number of expansions	9.2	13.2	14.1
Duty in millions of foot-pounds per 112 lbs. of coal, supposing coal to give up 11,000 heat-units per pound, taking 88% efficiency	112.1	113.4	114.8

Thermal units per indicator horse-power per minute, calculated from the temperature of the air-pump discharge	320.0	315.0	311.0
Coal per indicator horse-power per hour, supposing feed taken from hot-well, and the coal to give up 11,000 thermal units per pound.................................lbs.	1.74	1.72	1.70
Donkin's coefficient..............................	273.5	265.2	260.6
Disposal of heat used:—			
As indicated work..................per cent.	13.3	13.5	13.7
Rejected heat and error........... ,,	85.5	85.2	85.2
Radiation .... ,,	1.2	1.3	1.1

The average efficiency in the three trials is 91.5 per cent, and deducting 3½ per cent for the power required to work the air-pump and feed-pump, a net result of 88 per cent efficiency is obtained, which, as Mr. Mair remarks, is a higher value than what is generally obtained by a crank-and-flywheel engine when the pump-valves are tight.

## CHAPTER XLI.—HORIZONTAL COMPOUND CONDENSING CENTRIFUGAL PUMPING ENGINE.

CONSTRUCTED BY MESSRS. EASTON & ANDERSON, LONDON AND ERITH, FOR A PLANTATION IN DEMERARA.

(Cylinders 13 inches and 22½ inches in diameter, stroke 16 inches.)

This combined engine and pump is well adapted for erection on marshy ground, where powerful pumps of an ordinary description cannot be erected, due to the difficulty of providing suitable foundations. The engine and pump, figs. 706, were erected in 1884.

The engine is horizontal, and is fixed on a cylindrical casing, containing the pump, erected on a bed of concrete. The first and second cylinders are opposed to each other, connected to opposed cranks on the upper end of the vertical shaft, on the lower end of which the centrifugal pump is fixed. The whole is self-contained and independent of foundations.

The casing is of cast iron, 8 feet in diameter inside, 14 feet deep. It is formed with brackets cast on it, one at each side to carry the engine, the frame of which, generally of ⅞-inch metal, is bolted down to them. The first cylinder is 13 inches in diameter, and the second is 22½ inches in diameter, with equal strokes of 16 inches. The ratio of the cylinder-areas is as 1 to 3. The cylinders are fitted with ordinary slide-valves, and the first cylinder has in addition an expansion-valve on the back of the main slide. Steam is cut off at about 40 per cent in the first cylinder, and 80 per cent in the second cylinder. The working pressure of steam in the boiler is 75 lbs. per square inch. The connecting-rod is 32 inches long, or four times the length of the crank. The air-pump and condenser
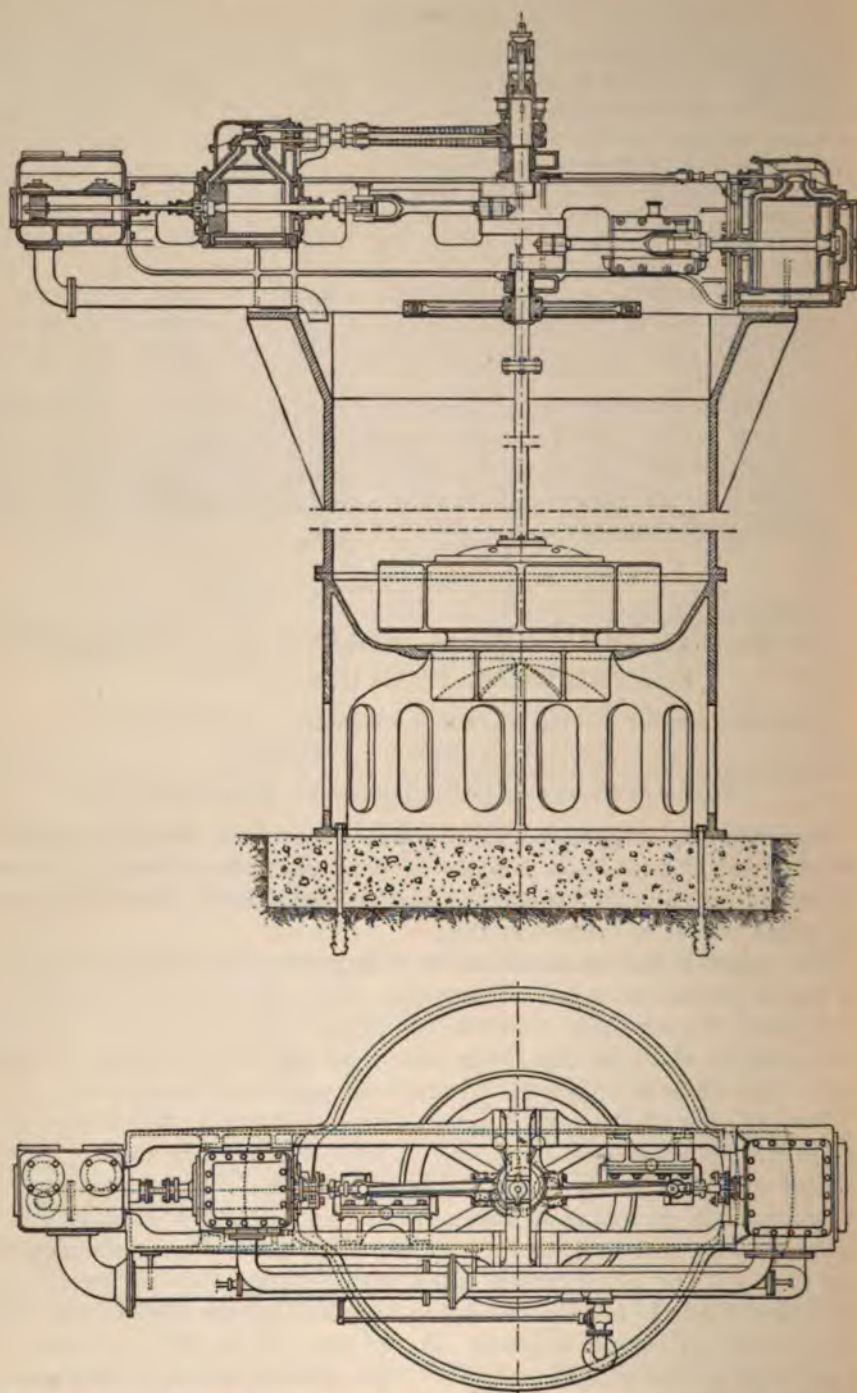
Figs. 706.—Compound Pumping Engine and Centrifugal Pump, by Messrs. Easton & Anderson, London and Erith.
Scale 1/48th.

are placed in line behind the first cylinder. The pump is $6\frac{1}{4}$ inches in diameter with a stroke of 16 inches, worked off a prolongation of the piston-rod. The exhaust-steam from the second cylinder is condensed on its way to the condenser by a jet of water provided for the purpose. The steam supply-pipe is 3 inches in diameter, of $7/16$-inch metal; the exhaust-pipe from the first cylinder is $4\frac{1}{4}$ inches, of $\frac{1}{2}$-inch metal; and the exhaust-pipe to the condenser is 6 inches, of $9/16$-inch metal. The two exhaust-pipes, the straight portions of which are about 11 feet and 15 feet long respectively, are formed each with an expansion-joint, to compensate for the difference of expansion of the pipes and the frame of the engine. Each joint is formed by conically enlarging the end of one of the pieces of pipe forming the joint, and connecting it to the end of the other piece by the medium of a transverse sheet of copper formed with a central open-ing of the size of the pipe, bolted to the two ends. The elasticity of the copper sheet supplies the necessary yielding. As the reciprocating parts are exactly opposed, they counterbalance each other. The injection-pipe to the condenser is $2\frac{1}{2}$ inches in diameter, $7/16$ inch thick. With the aid of a small fly-wheel, 5 feet in diameter, the engine works with ease and steadiness. The supply of condensing water is drawn from the water over-flowing the casing.

The centrifugal fan is 6 feet in diameter, 16 inches deep; formed with eight blades of the involute curve. It is fixed on a $3\frac{1}{2}$-inch vertical spindle, united by a flange-coupling to the crank-shaft. The crank-shaft is 4 inches in diameter at the journals. It is suspended from an overhead cast-iron girder fixed to the principal frame, by an "onion" or segmental-spherical bearing on the end of a suspending bolt, over which a gun-metal cap is placed, cottered to the upper end of the shaft. This bearing takes the weight of the crank-shaft, spindle, and pump-fan.

The engine and pump make a maximum of 115 revolutions per minute, and an average of 93 revolutions. The engine weighs, with the fly-wheel, 6 tons 7 cwts. The fly-wheel alone is 7 cwts. The engine and pump together, without the casing, weigh $9\frac{1}{4}$ tons.

OTHER SPECIAL STEAM ENGINES.

CHAPTER XLII.—PAIR OF HORIZONTAL COMPOUND REVERSING RAIL-MILL ENGINES.

CONSTRUCTED BY MESSRS. TANNETT WALKER & CO., LEEDS.

(PLATE XIII.)

(Cylinders 34 inches and 60 inches diameter, 60 inches stroke.)

The pair of compound reversing rail-mill engines, constructed for the works of Wendel & Co., in Lorraine, and in France, are illustrated in Plate XIII. The engines are horizontal, tandem fashion. The second cylinder of each engine is behind the first, in a line, and the main shaft is at the other end, the two engines, side by side, being coupled to cranks on
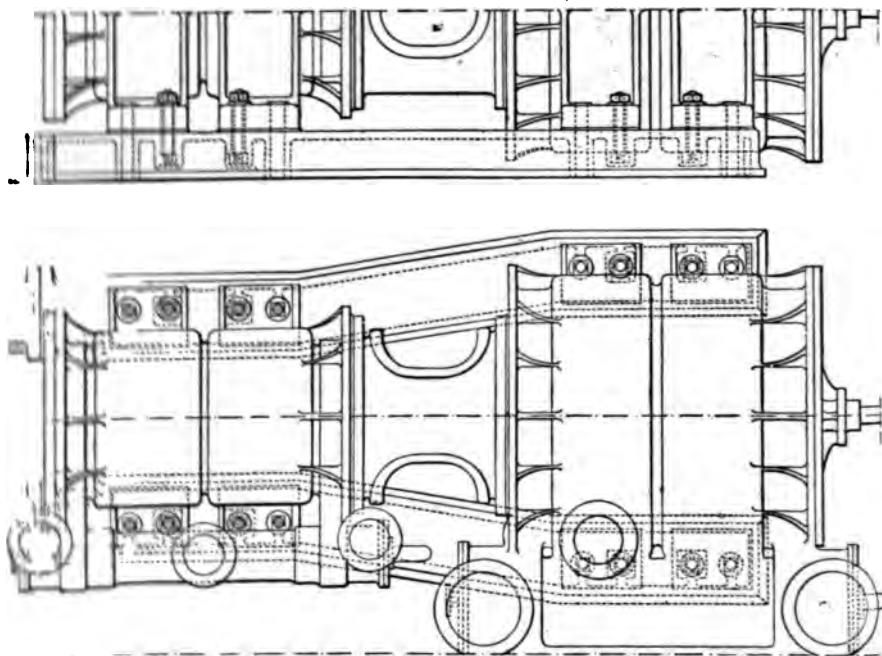
Fig. 707.—Tannett Walker & Co.: Rail-mill Engines. Bed-frame and Cylinders. Scale 1/48th.

the shaft at right angles. The cylinders are thoroughly steam-jacketed and lagged, and the engines are fitted with piston-valves, and are reversible by the employment of shifting-link motions, with hydraulic gear. A "condensation engine" is in operation beside the rail-mill engine, for the purpose of condensing the exhaust steam from the latter, in addition to its work as an accessory condensing engine.

CONSTRUCTED BY MESSRS. TANNETT WALKER AND CO., LEEDS.

RAIL-MILL ENGINE.
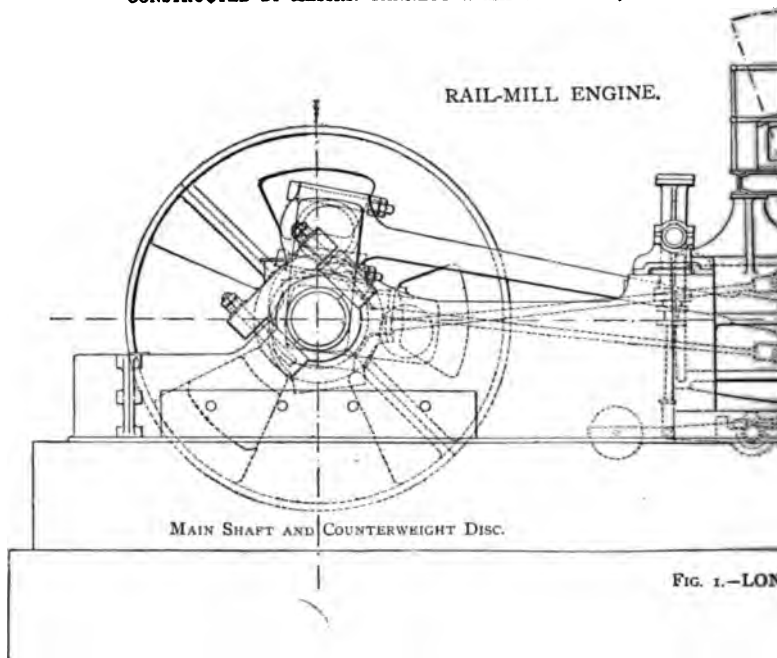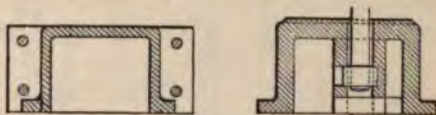
MAIN SHAFT AND COUNTERWEIGHT DISC.

FIG. 1.—LON

FIG. 2.—PLAN.

TION.
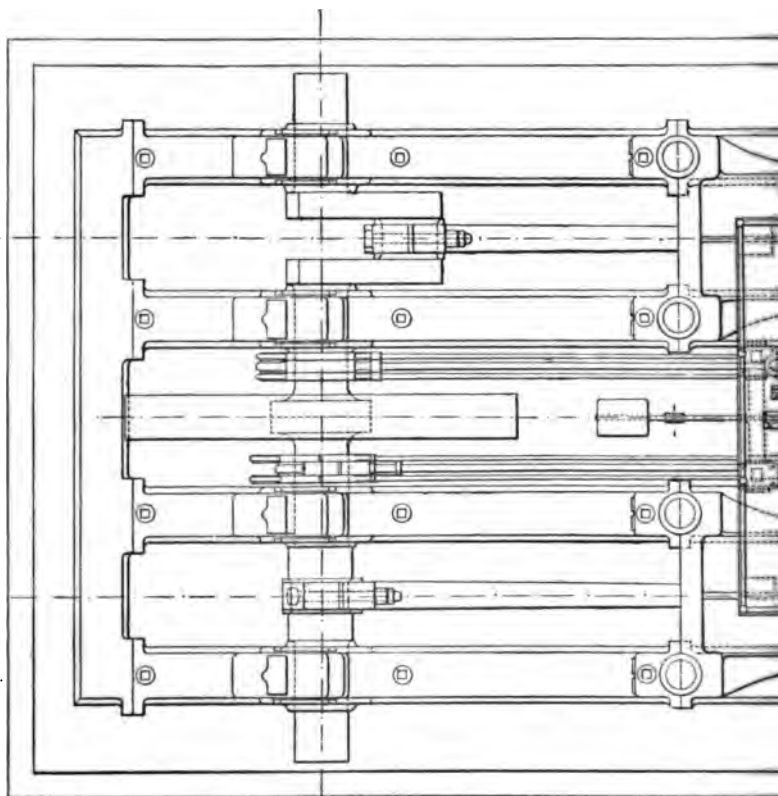
The first cylinder of each mill-engine is 34 inches in diameter, and the second cylinder is 60 inches, with a common stroke of 5 feet. The areas of the cylinders are as 1 to 3.11. The working speed is from 100 to 120 turns, or from 1000 to 1200 feet of each piston per minute. The engines are designed to work with steam of from 90 lbs. to 100 lbs. pressure per square inch.

The bed-frame, of cast iron, figs. 707, 708, and 709, consists of four longitudinal hollow girders, corresponding to and severally connected to the four main bearings, bound at the end next the main shaft by a cross member. At the cylinder end they are bound by the cylinders, which are bolted down to them. The centre-lines of the two engines are 10 feet apart. The total length of the

Figs. 708.—Rail-mill Engines: Sections of Bed-frame.
Scale 1/24th.

framing is 41½ feet. The width at the main shaft is 16 feet, augmented to 17¾ feet at the other end, to adapt itself to the larger second cylinders. Each girder is constructed in three pieces, bolted and rung together. The piece at the main shaft is 4 feet high and 15 inches wide, comprising in one casting with it the pedestal for the bearing, figs. 709. It consists of a top
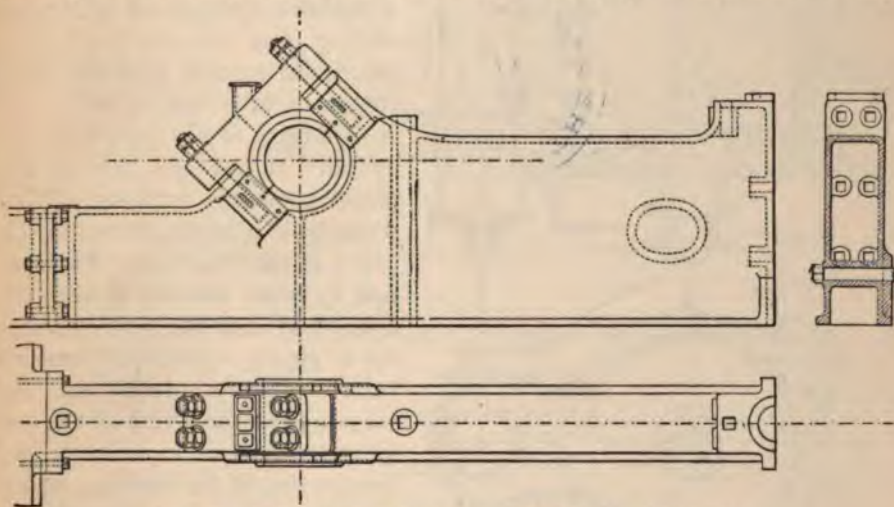
Figs. 709.—Rail-mill Engines: Bed-frame and Main Pedestal. Scale 1/48th.

and two sides, of 1½-inch metal, and is open at the bottom. The end cross junction piece is 2½ feet high, 15 inches wide, of 1½-inch metal.

The base of each piece is 19 inches wide. The middle pieces, figs. 707 and 708, have the same widths, but are only 11¾ inches high, and are of 1¼-inch metal. The end pieces under the cylinders are also 11¾ inches high, made up to 12 inches at the supports for the cylinders; but they are of 2-inch metal, and are 18 inches wide, and extended to 22 inches wide at the base. Each cylinder is bolted down to two frame-pieces by two pairs

of 2½-inch bolts at each side, one bolt of each pair taking into a nut within the frame, as shown in figs. 707, and the other being carried down through the foundation, and secured with a plate. The middle piece of each girder is fastened to the first and third pieces with four 1½-inch bolts and nuts, through flanges 3½ inches thick. The end cross-piece is bolted to each girder with six 1½-inch bolts and nuts, and flanges 1¾ inches thick, made up to a thickness of 4 inches at each bolt.

The fastenings of the cylinders are not required to take the longitudinal stress of the engine. This stress is provided for and resisted through the direct connection of the cylinders with the main-shaft girder sections, for which purpose a massive cylindrical guide-bar casting, figs. 711, is interposed, being one casting with the front covers of each first cylinder. It is of course firmly bolted to the cylinder at one end, and to the girder segments with the aid of wrought-iron hoops, shown in the plans, at the other end. The second cylinder likewise is directly connected with the first cylinder by a strong cylindrical casting bolted to the cylinder covers. By these means the stress of the engines is taken up in a direct line, irrespective of the framing, which does little else than support the cylinders and keep them in line. The centre-lines of the cylinders are 2½ feet above the level of the frame.

The first cylinder, figs. 710, 34 inches in diameter, is 1½ inches
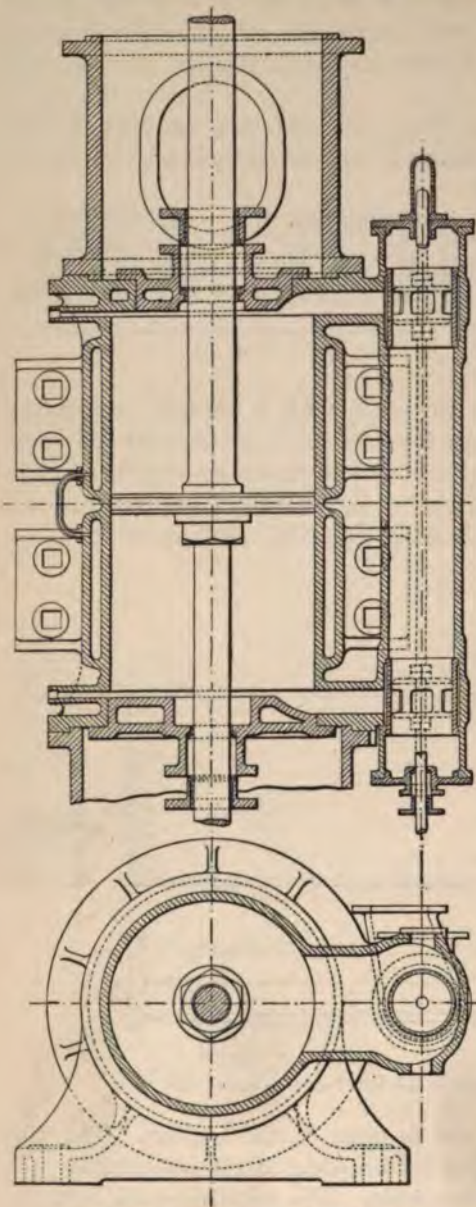
Figs. 710.—Rail-mill Engines: First Cylinder in Section. Scale 1/32d.

thick. It is 5 feet 4 inches in length between the covers, comprising the stroke of 5 feet, the 3-inch thickness of the piston, and ½ inch of direct clearance at each end. The jacket is of 1½-inch metal, and incloses a 2-inch

steam-space. It is cast in one with the cylinder, and is divided lengthwise into two sections at the mid length. It does not reach to the flanges of the cylinder, but is stopped 7 or 8 inches short of them. The casting of the cylinder is thereby simplified, and the difficulties incidental to the construction of ordinary jacketed cylinders cast in one piece are obviated. The front end of the cylinder is bored out to $34\frac{1}{2}$ inches in diameter. The cover is turned to fit it, and is 6 inches deep, of $1\frac{1}{2}$-inch metal outside and inside, inclosing a 3-inch steam-space. It is fastened to the cylinder with twenty $1\frac{1}{4}$-inch bolts and nuts, pitched at about 6 inches apart. The cover of the back of the cylinder is 5 inches deep, of $1\frac{1}{2}$-inch metal inside and outside, inclosing a 2-inch steam-space. It is 2 feet 2 inches in diameter, let into the end of the cylinder, which is formed with a steam-space like that of the cover.

The guide-bar casting, figs. 711, is cylindrical, with side openings to lighten it, and give access to the crosshead and stuffing-box. It is
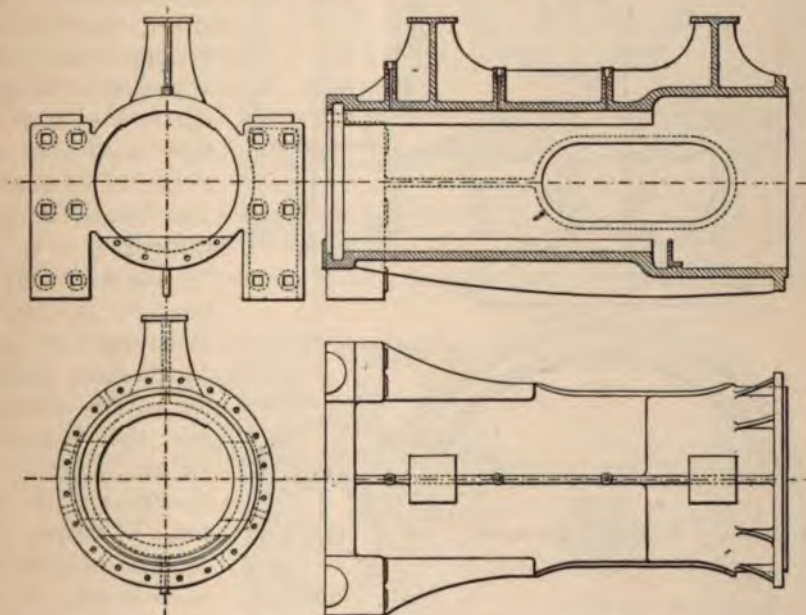
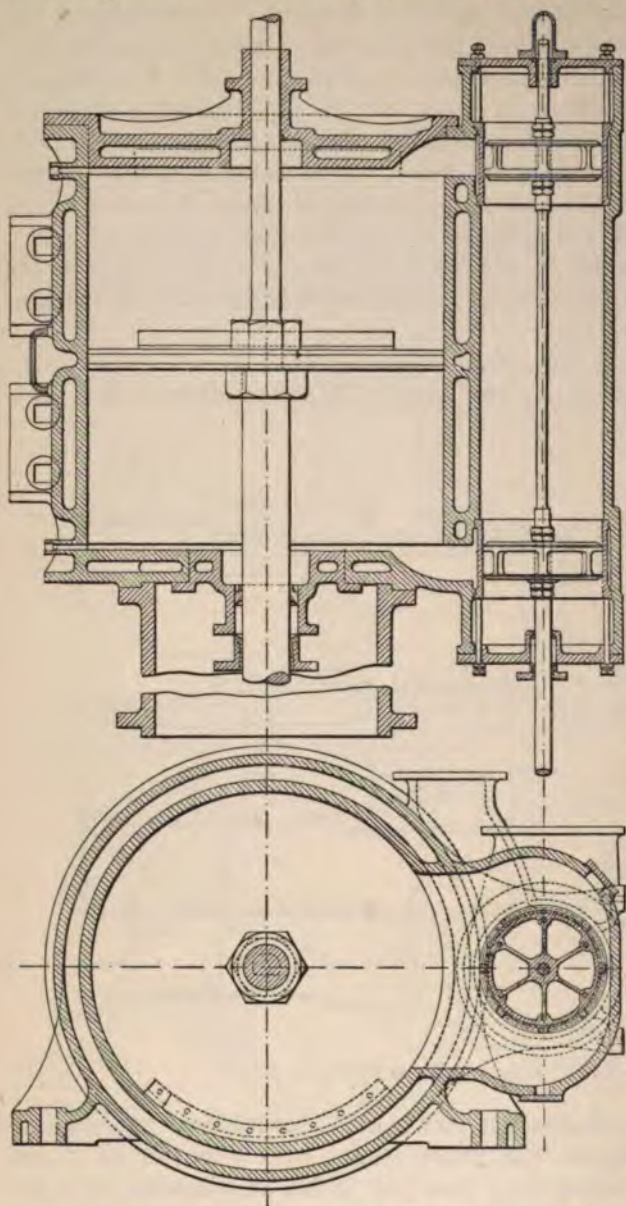Figs. 711.—Rail-mill Engines: Guide-bar Casting.   Scale 1/48th.

$36\frac{1}{2}$ inches in diameter inside, $1\frac{3}{4}$ inches thick, having two guiding surfaces, upper and lower, for the slides, bored to a diameter of 2 feet $11\frac{3}{4}$ inches. It is enlarged to 3 feet $7\frac{1}{2}$ inches in diameter next the cylinder, to which it is bolted with a flange $2\frac{1}{4}$ inches thick, and twenty $1\frac{1}{2}$-inch bolts and nuts. The casting is 9 feet 9 inches long between the end faces. At the other end it is formed with two wings, each 15 inches wide and 3 feet 9 inches high, by which it is fastened to the pedestal castings with six bolts, $2\frac{1}{2}$ inches square, for each wing, and, in addition, a wrought-iron ring, 2 inches square in section, 10 inches in diameter inside,

shrunk over the semicircular heads, one on each wing and pedestal casting. The wings rest on the ends of the middle sections of the bed. A well is formed at each end of the lower guiding surface for the collection of lubricating oil.

The intermediate casting between the first and second cylinders is cylindrical, 3 feet 1 inch in diameter and 3 feet 2½ inches long, between the end faces, of 2½-inch metal. Three openings are made, giving access to the stuffing-boxes. It is bolted to each cylinder with twenty 1½-inch stud-bolts and nuts, pitched at about 7½ inches between centres.

The second cylinder, figs. 712, 60 inches in diameter, are 5 feet 4 inches long between the covers—comprising the length of stroke, 5 feet, the thickness of the piston, 3 inches, and ½ inch of clearance at each end. It is of 1¾-inch metal; the steam-jacket also is 1¾ inches thick, and it incloses a 2½-inch steam-space. The jacket and the cylinder covers are con-

Figs. 712.—Rail-mill Engines: Second Cylinder, Sections. Scale 1/32d.

structed similarly to those of the first cylinder. The front cylinder-cover is 2 feet 2 inches in diameter. The back cover is ⅛ inch larger in diameter than the bore of the cylinder. They contain 2-inch steam-spaces, with 1¾-inch metal. The back cover is fastened with a flange 2 inches

thick, and thirty 1¼-inch bolts and nuts, pitched at about 7 inches between centres.

The steam-ports of each cylinder are short, as they are controlled by separate piston-valves. Those of the first cylinder are 4 inches by 16 inches, and those of the second cylinder are 6 inches by 33 inches; having sectional areas about ¹/₁₄th of those of the respective pistons. The steam is cut off in the first cylinder at from ⅝ths to ¾ths of the stroke.

The piston-valves, figs. 713, are in pairs, comprising one valve for each end of the cylinder, respectively 10 inches and 20 inches in diameter, working in liners lodged within cylindrical casings, 11 inches and 21 inches

Figs. 713.—Rail-mill Engines: Piston-valves. Scale 1/16th.

in diameter, and 1¼ inches and 1¾ inches in thickness. They are correctly balanced, and keep fairly tight. The valve-rods are of steel, 2 inches in diameter, enlarged to 2½ inches at the valves, which are fixed on the
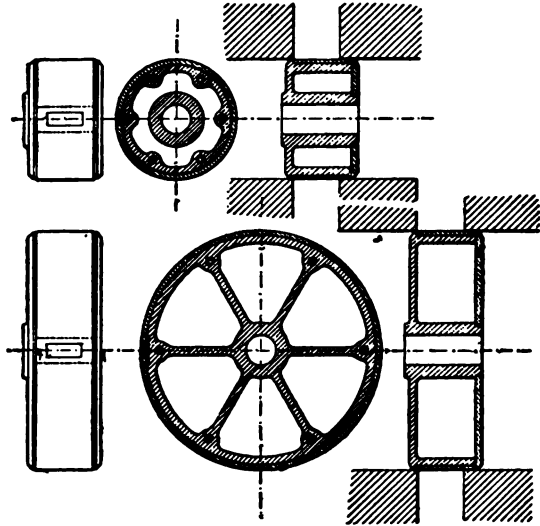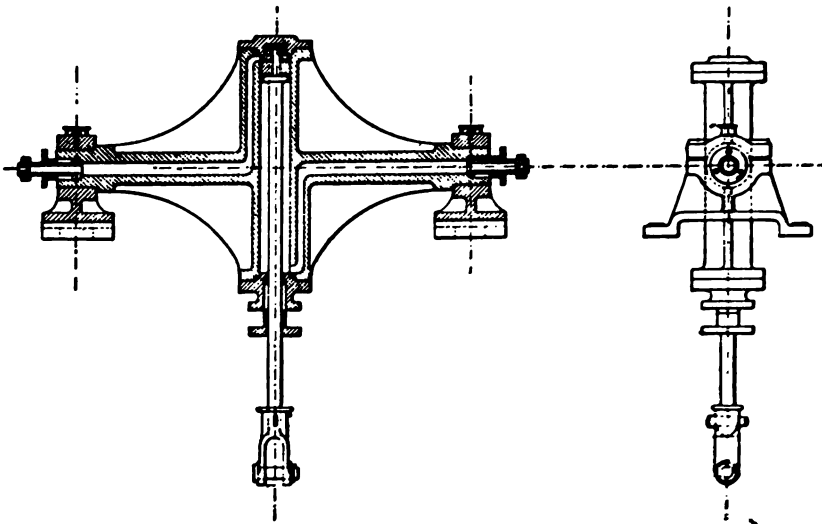
Fig. 714.—Rail-mill Engines: Hydraulic Reversing Gear. Scale 1/32d.

rods by double nuts at each face, screwed on the enlarged parts. The valves are worked by six eccentrics, 31 inches in diameter, with 9 inches of throw, three to each engine; forming, with the link, a reversing link-

motion. The rods of two of the eccentrics are pinned to one end of the link, one at each side of the link, and the third is pinned to the other end. Thus, the connections are symmetrical, and the stress is exactly central at each end of the link: obliquity of stress is obviated. The reversing link
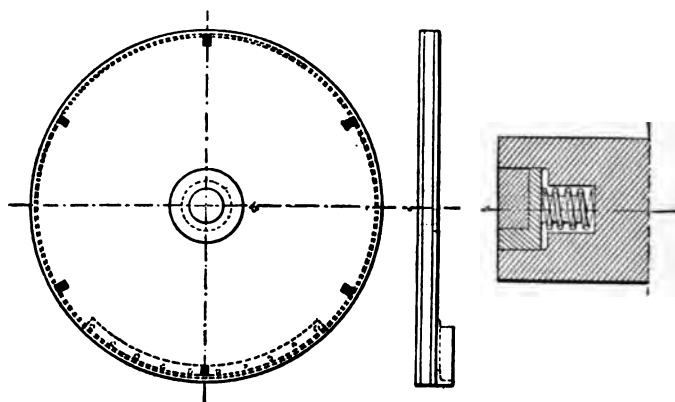
Figs. 715.—Rail-mill Engines: Second Piston, Scale 1/32d; and detail of Packing-ring and Spring, Scale 1/4th.

has a slot 3 feet in length for working the valves, the maximum travel of which is 9 inches. The links are counterweighted, and the reversing of the links is effected by the power of a hydraulic cylinder, figs. 714, 5 inches in diameter, cast with water passages, and hung on trunnions, to suit the sway of the weigh-bar. The piston is packed with leather, and its rod passing
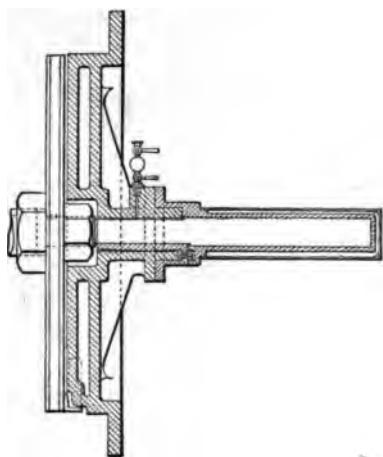

Fig. 716.—Rail-mill Engines: Second Piston fastening on Rod.

through a stuffing-box is pinned to the end of the weigh-bar on the reversing shaft, from which the links are sustained. The working hydraulic pressure is 700 lbs. per square inch; and the supply is taken from the accumulator and pumps which are almost always provided in a large iron or steel works. In the absence of hydraulic power, steam with a cataract can be used.

Steam from the boiler is brought in a 13-inch cast-iron pipe, 1 inch thick, fitted with a gridiron steam stop-valve, and an equilibrium-valve for regulating the supply of steam by hand, at the same time that the reversing lever is handled. The pipe branches into 9-inch pipes, one to each first cylinder. The steam is delivered into the middle part of the valve-cylinder, from which it is distributed to the steam-cylinder by the piston-valves, and is exhausted at each end of the valve-cylinder into 10-inch pipes.

From these it is taken by a 12-inch pipe into the valve-cylinder of each

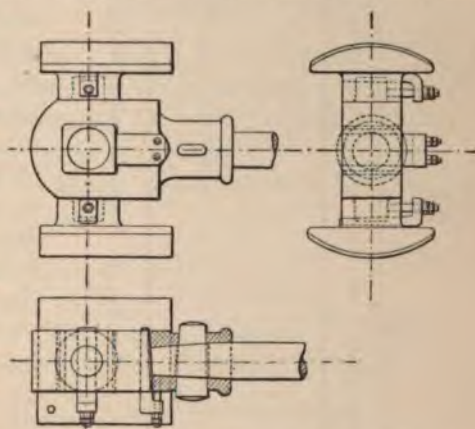second cylinder. Thence it is finally exhausted, by 18-inch pipes, to the condenser.

The pistons, figs. 710, 712, 715, and 716, are each a solid wrought-iron disc 3 inches thick, grooved at the circumference for a packing-ring 1¾ inches wide, and 1⅛ inches thick. It is cut at one place, and made tight with a brass fitting. It is pressed outwards by six helical springs of ⅛-inch round steel, ⅞ inch in diameter and 1 inch long. The pistons are provided with brass bearing-pieces of 3-inch angle-brass, ¾ inch thick, riveted to the lower part of the piston, and taking a bearing on the cylinder.

The piston-rod is of steel, one piece for the two cylinders. It is of three diameters, 8 inches between the first and second pistons, 6 inches between the first piston and the crosshead, and 5 inches for the prolongation through the back of the second cylinder, to support the piston. The middle diameter, 8 inches, is adopted for convenience of erection and of dismounting. The total length of the piston-rod is 24 feet 11 inches. The first piston is fixed against a collar by a collar-nut 5 inches thick; the second piston is fixed between two nuts, as shown in fig. 716. The prolonged portion of the piston-rod is flattened at the lower side, for properly supporting the piston, reducing the depth of the rod to 4¼ inches. It slides over a brass bearing close to the cylinder-cover, and is inclosed by a cast-iron tube, fastened to the cover, within which it reciprocates.

The crosshead, figs. 717, is of iron, forged solid, and is brass-bushed to give a bearing 7 inches in diameter and 10 inches long for the connecting-rod. The bush is set up by means of a cotter through the crosshead. It is socketed to receive the piston-rod, which is tapered from 6 inches to 5 inches in diameter for a length of 13 inches, and is fastened by a cotter 12 inches long, tapered from

Figs. 717.—Rail-mill Engines: Crosshead. Scale 1/32d.

5¼ inches to 4½ inches wide, 1½ inches thick. The slides are 22 inches in length by 21 inches wide, rounded to the diameter of the guide-bars, 2 feet 11¾ inches, and faced with brass wearing-pieces.

The connecting-rod, figs. 718, is of wrought iron, 13½ feet long, or 5.40 times the length of the crank; having a uniform taper from 10 inches in diameter at the large end to 7½ inches at the smaller end. It is made with cap-and-bolt fastenings for the large or crank end, giving a bearing 18 inches in diameter and 12 inches long. The butt and the cap are 10 inches thick and 31 inches wide. They are bored out to receive the brasses, which are of uniform thickness, 1½ inches; and are fitted each with a stud outside to enter a hole in the iron. The two bolts are 4 inches in

diameter. each with a nut and jam-nut, and a safety-pin through the bolt. A small joggle is fixed in the neck of each bolt, which takes into a recess in the cap. A brass oil-box, figs. 719. $9\frac{3}{4}$ inches by 3 inches, and 3 inches deep. is screwed on the top of the butt, from which the lubricant is conducted through the $\frac{1}{2}$-inch capillary tubes to the journal. The crosshead end is forked. the forks being $3\frac{1}{2}$ inches thick and 10 inches apart, with a 7-inch steel bolt. The bolt is formed with a round head let into one of the forks, tapering from 8 inches to $7\frac{1}{2}$ inches in diameter, and a collar nut on the other end, $4\frac{1}{2}$ inches thick, secured by a pin through the bolt.

The main shaft is of hammered scrap iron, and is made in two half-lengths, which are bolted together at the middle. It is 18 inches in diameter throughout, including the four journals, two to each crank, which are 22 inches in length; and the crank-pins, which are 12 inches long. The crank arms are 9 inches wide by 22 inches in section. The fly-wheel, or, properly speaking, the counterweight-disc, is 11 feet in diameter, and 15 inches wide at the rim. It is fixed on the shaft, in the middle.

The gross weight of the pair of rolling-mill engines is 154 tons, of which the four parts of the bed, with the main bearings, weigh together 24 tons. The power developed in rolling rails is generally from 1500 to 2200 indicator horse-power; the maximum power exerted has risen to 3400 horse-power. The consumption of steam is at the rate of about 30 pounds per indicator horse-power per hour; or a total of from 720 to 1060 cubic feet per hour. The mill is capable of turning out from 300 tons to 400 tons of rails in a shift of from 10 to 12 hours.

The price of the engines is £5500, or £35, 14s. per ton of weight.

The foundation is 18 feet deep. It is of stone found in the neighbourhood: granite and freestone, which would have cost in this country £2500.
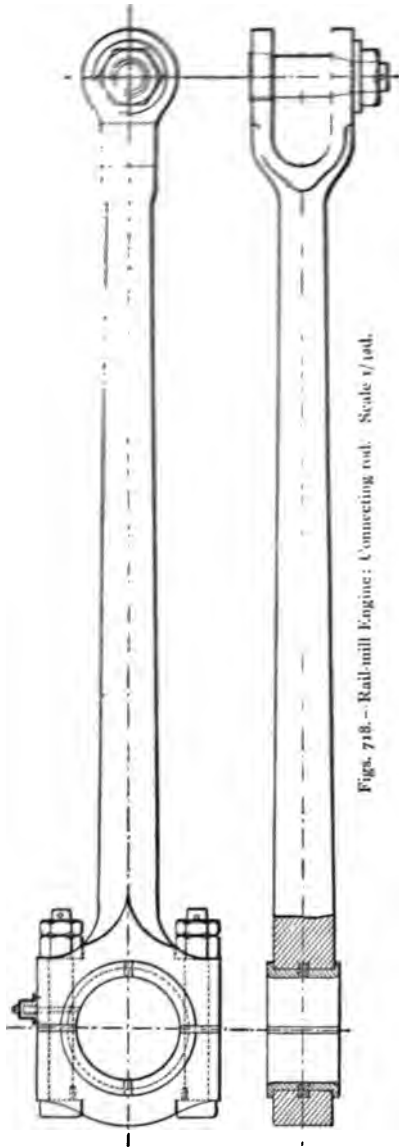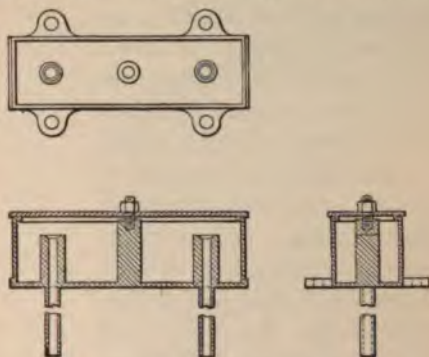
Fig. 718.—Rail-mill Engine : Connecting-rod.   Scale 1/10th.

It cost much less where it was built. Similar engines are erected in York-shire on concrete foundations, with a top layer of monolith or Bramley Fall stone, costing from £800 to £1000.

Condensation Steam Engine.—The accessary condensation engine, figs. 3 and 4, Plate XIII., auxiliary to the mill engine, condensing its exhaust steam, is a horizontal engine of two single 16-inch cylinders, with a stroke of 30 inches, coupled to two disc-cranks at right angles on one shaft, 7 inches in diameter, with an inter-mediate fly-wheel 9 feet in diameter. The piston-rods are prolonged through the back cylinder-covers, and at both ends they are sustained on slipper guides, being open above. Each rod reciprocates a three-arm bell-crank of 3 feet 2 inches radius, work-ing a single-acting air-pump 16 inches in diameter, and a circulating-pump, 2 feet 1 inch in diameter, with a stroke of 30 inches, placed vertically,

Figs. 719.—Rail-mill Engine: Oil-box for Connecting-rod.   Scale 1/8th.

one on each side of a surface-condenser, 2 feet 8 inches by 5½ feet, and about 10 feet high. Each condenser holds 1596 condensing tubes ¾ inch in diameter. The engines make from 40 to 48 turns, or from 200 feet to 240 feet of piston per minute, or even more if required.

The weight of the condensation engines complete is 62 tons. The price is £1950, or £31, 9s. per ton of weight.

Chapter XLIII.—HORIZONTAL STEAM ENGINE FOR SUGAR MILLS, of 90 Nominal Horse-power.
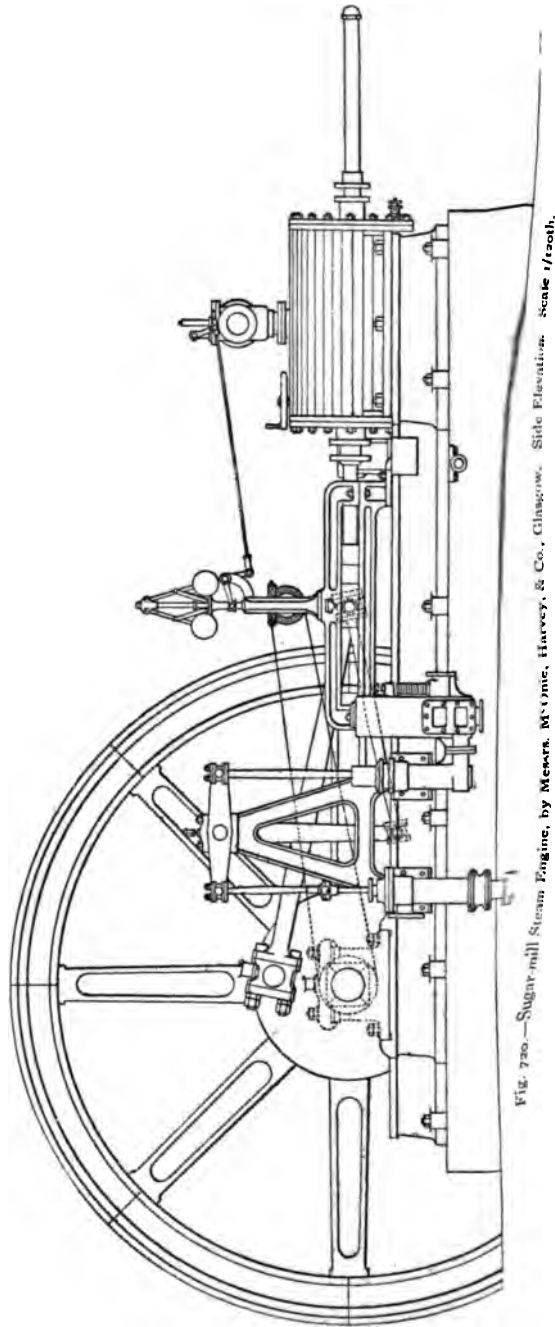
CONSTRUCTED BY MESSRS. MᶜONIE, HARVEY, & CO., GLASGOW.
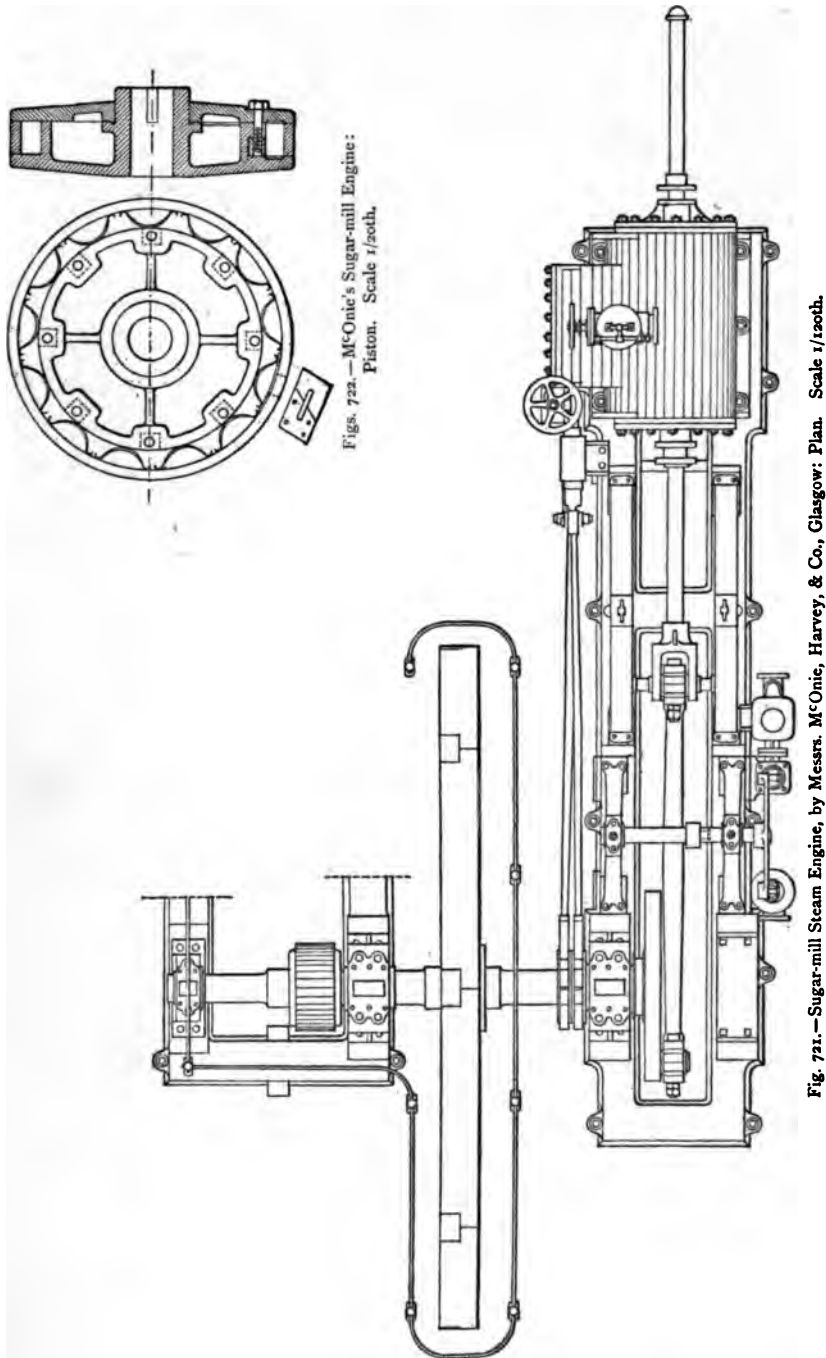
(Cylinder 30 inches in diameter; 4-feet stroke.)

This is a single-cylinder engine, figs. 720 and 721, having a massive bed-frame, cast in one piece, 24¼ feet long, and 4 feet wide at the base, except at the main bearing, where it is 4 feet 9 inches wide. It is 18½ inches deep, and 11 inches wide across the top of each limb; 1¼ inches thick at the top, 1 inch at the sides, and strongly ribbed transversely. It is laid on a timber bed of oak, tenoned and bolted, 18 inches deep, on the top of the foundation. It is bolted down with twelve 1¾-inch bolts. The cylinder is 30 inches in diameter, with a stroke of 4 feet, of 1⅜-inch metal. The normal speed is at the rate of 300 feet of piston per minute, equivalent to 37½ turns per minute. The working pressure in the boiler is 80 lbs. per square inch, and when steam is cut off at 75 per cent of the stroke, the usual period of admission, 500 indi-cator horse-power is exerted. The nominal power of the engine is 90 horse-

power, reckoned at the rate of 8 square inches of piston-area per nominal horse-power. The steam-pipe is 7 inches in diameter, of ¾-inch metal, fitted with an equilibrium valve, commanded by a governor driven by a band from a pulley on the main shaft, at a speed of 56 revolutions per minute. The exhaust-pipe is 9 inches in diameter, of ¾-inch metal.

The slide-valve is worked by an ordinary reversing link-motion, with which steam may be cut off at from ¾ths to ⅓d of the stroke. The piston, figs. 722, is of cast iron, 6 inches thick at the circumference and 8 inches at the centre. The thickness of metal is 1 inch. The packing-ring is of cast iron, of an ordinary marine type, 3½ inches wide and ⅞ inch thick uniformly, cut at one place obliquely, and jointed with a joggle. It is pressed outwards by thirteen segmental steel springs abutting on an inner ring, 1⅛ inches thick, cast on the body of the piston. The junk-ring is fastened to this ring with eight 1⅛-inch bolts, with brass nuts, 2 inches thick, inserted in recesses formed in the ring. The piston-rod is of ingot steel, 4¾ inches in diameter, cottered into the piston with a taper of ⅛ inch in diameter for a length of 9½ inches. The eye is 8 inches in diameter. The cotter is secured in its place by the junk-ring, which encircles it. The piston-rod is prolonged and passed through the back cylinder cover, for additional support, with a

Fig. 720.—Sugar-mill Steam Engine, by Messrs. M'Onie, Harvey, & Co., Glasgow. Side Elevation. Scale 1/120th.

view to secure more nearly uniform wear of the cylinder than would other-

Figs. 722.—McOnie's Sugar-mill Engine: Piston. Scale 1/20th.

Fig. 721.—Sugar-mill Steam Engine, by Messrs. McOnie, Harvey, & Co., Glasgow: Plan. Scale 1/120th.

wise be the case. The crosshead is of the ordinary forked type, keyed on

the end of the piston-rod. The pin offers a journal 5 inches in diameter and 7 inches long; and carries a pair of slide-blocks, one at each side, between a pair of guide-bars of cast iron, which are bolted together and to the bed. The blocks are 14 inches long, and the guide-bars are 7 inches wide. The connecting-rod is of ingot steel, 4¾ inches in diameter at the ends and 6½ inches at the middle. It is 10 feet long, or five times the length of the crank. It is constructed at each end with a flat butt, cap, and bolts, and square brasses, giving bearings 5 inches by 7 inches at the cross-head end, and 5½ inches by 7 inches at the crank-pin. The main shaft is of ingot steel, 9½ inches in diameter at the two main journals, which are
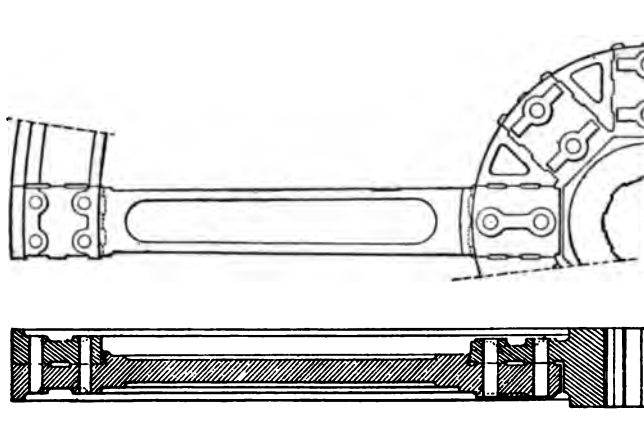
Figs. 723.—McOnie's Sugar-mill Engine: Fly-wheel, Detail. Scale 1/32d.

15 inches long. The main pedestal is carried on the engine bed; the outer pedestal is carried on the intermediate bed. The shaft is 13 inches in diameter at the fly-wheel. The first spur-pinion of the intermediate gear is of crucible cast steel, 24½ inches in diameter, 13 inches broad, with 4½ inches of pitch. It is keyed on the main shaft, which has a third and outermost bearing on the intermediate bed-frame. The crank-disc is of crucible cast steel, 5 feet in diameter and 5½ inches wide at the rim, counter-weighted to balance the crank-pin and the connecting-rod. The crank-pin is of steel, 5½ inches by 7 inches long at the journal. The shank of it is let with a slight taper into the disc, and riveted over. The fly-wheel, figs. 723, is of cast iron, 18 feet in diameter. The body of the rim is 8 inches thick, flanged to 12 inches wide at the outer side; and to 9½ inches at the inner side. It is 15 inches deep radially. The segments are united to each arm with four turned 2-inch bolts and nuts. The centre is 5 feet in diameter, 13¼ inches wide, with 6 inches of metal round the bore; and a disc 2¾ inches thick, to which each arm is fastened with two 2½-inch bolts and nuts. The wheel is keyed on the shaft with eight wrought-iron keys, 2¾ inches wide, let ¼ inch into the metal of the eye, and applied to flats on the shaft. All the bearings are of gun metal.

Two single-acting pumps, each 6½ inches in diameter, with a 16-inch

stroke, are fastened to the side of the frame-bed, and are worked off the crosshead through a weigh shaft and arms, 4½ feet and 1½ feet long. One pump, with plunger, supplies feed-water to the boiler; the other, with bucket, lifts cold water.

The gearing is compound, and reduces the angular speed in the ratio of 25 to 1. The rollers are 32 inches in diameter and 6 feet long; the gudgeons are of ingot steel, having 15-inch journals 18 inches long. The hourly duty of the mill under normal conditions is a delivery of 3000 gallons of juice, which, at 10° Baumé, and with "triple effet," or vacuum-pan concentration, gives 2 tons of sugar. But, in a recent emergency, a precisely duplicate mill in Demerara yielded 4560 gallons per hour—an unfairly heavy duty.

The weight of the engine complete is 39½ tons, of which the frame-bed weighs 6½ tons, and the fly-wheel weighs 16 tons. The total weight of the plant, including the engine, exclusive of spare plant, is 212 tons.

CHAPTER XLIV.—PAIR OF HORIZONTAL WINDING ENGINES AND DRUM,

ERECTED AT LADY WINDSOR PIT, BLACK ROCK COLLIERY, YNISYBWLL, PONTYPRIDD, SOUTH WALES.

DESIGNED AND CONSTRUCTED BY MESSRS. ROBERT DAGLISH & CO., ST. HELEN'S, LANCASHIRE.

PLATE XIV.

(Cylinders 42 inches in diameter, stroke 7 feet; drum 33 feet in diameter.)

These engines, Plate XIV. and fig. 724, are horizontal, and connected to the drum-shaft at each end. The drum is of the double conical type, on the patent of Mr. George Heaton Daglish. The principal speciality of these winding engines is embodied in the motion adopted for working the steam and exhaust valves, first employed by Messrs. Daglish in 1877. One cylinder with its valve-gear is shown in figs. 725 and 726. The leading feature of the valve-motion is the conversion of the ordinary sliding motion given to slide valves into the lifting motion of the equilibrium valve. A long flat parallel bar, carried in guide-frames over the two valve-boxes of each cylinder, and passing through the slotted heads of the spindles, has a reciprocating motion communicated to it by the ordinary link-motion. Cast-steel cams are bolted to these rods, one to each valve, by which the valves are lifted for the admission of steam. The position of each cam is to a limited extent adjustable to the most suitable position for properly timing the lifting of the valve, which can be done with the greatest degree of nicety. A friction-roller of cast steel is pinned in the upper part of each slot, to take the action of the cam in opening the valve. The point of the cam—the part which first comes into contact
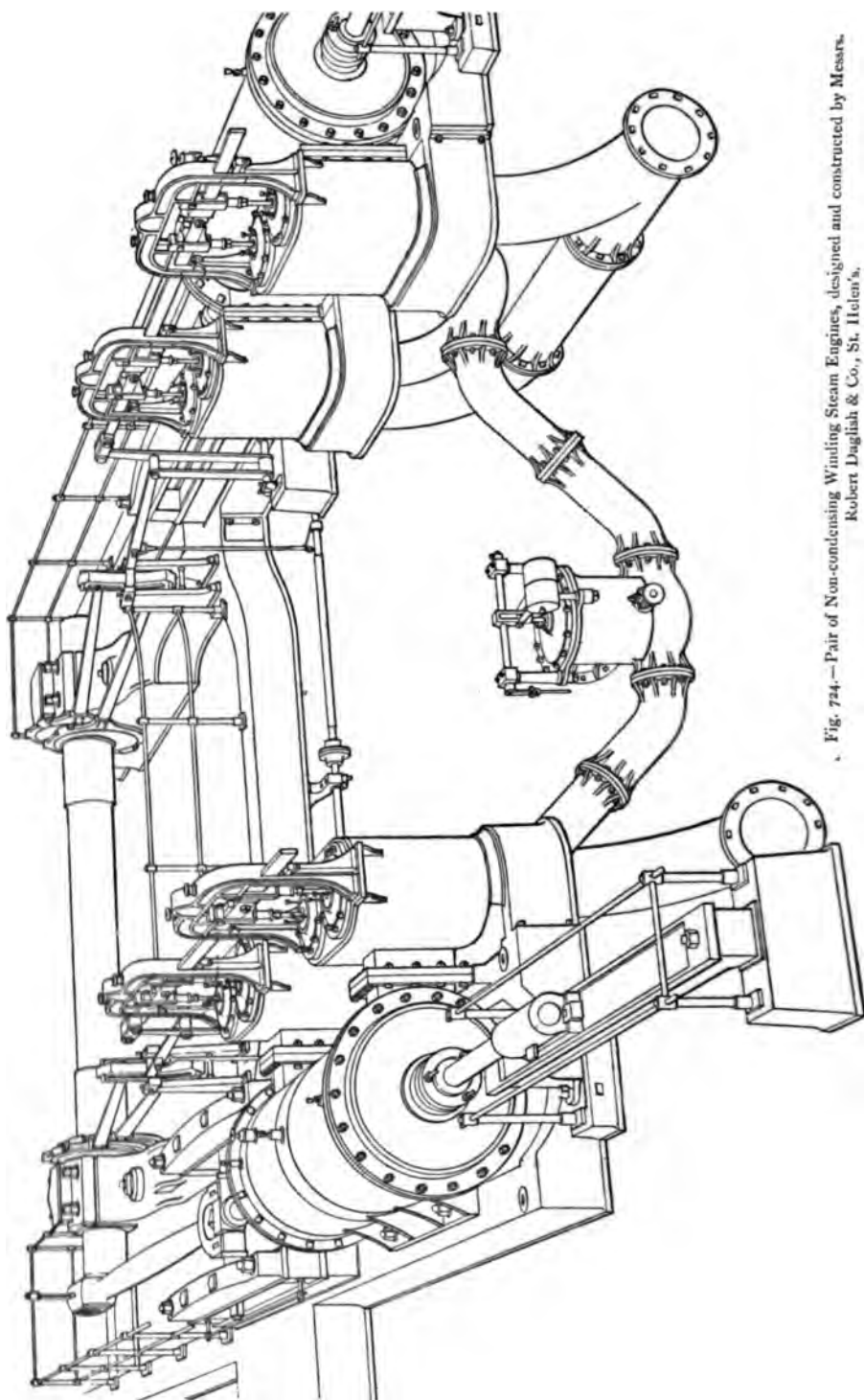
Fig. 724.—Pair of Non-condensing Winding Steam Engines, designed and constructed by Messrs.
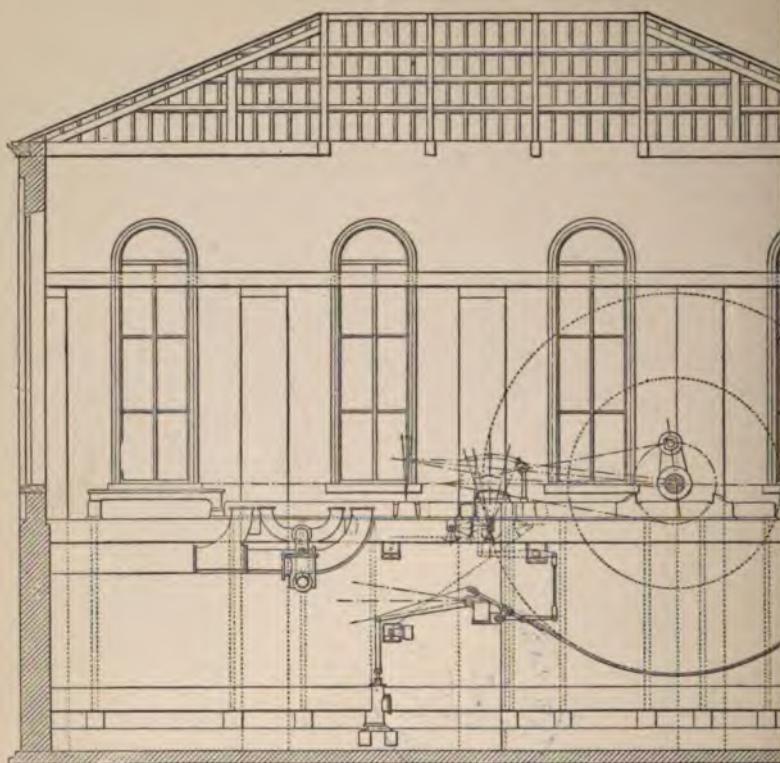Robert Daglish & Co., St. Helen's.
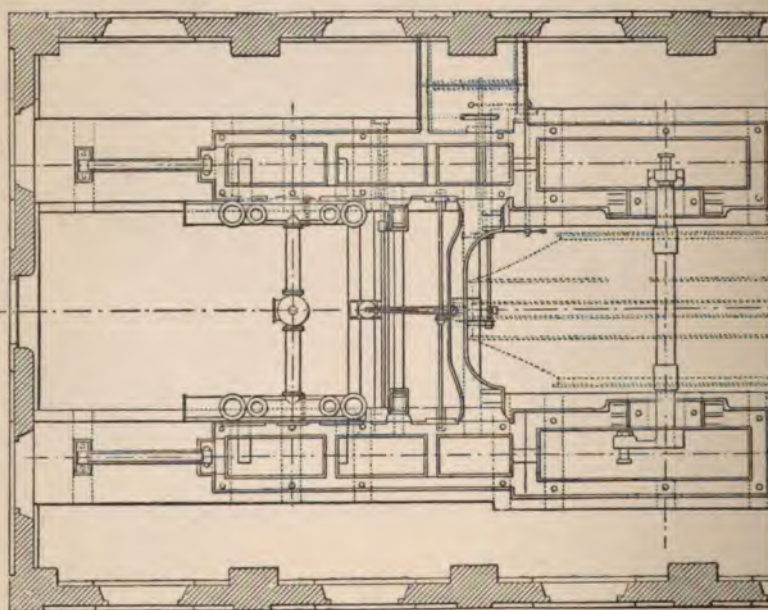
Fig. 1.—LONGITUDINAL SECTION THROUGH ENGINE-HOUSE. Scale


Fig. 3.—PLAN. Scale 1-192nd.

with the roller—is of a fine wedge-form, so as with great force to lift the valve off its face, against the pressure of the steam. When the opening is effected there is but the weight of the valve, with its spindle and socket, to be supported; and the form of the remainder of the cam is correspondingly obtuse, so as rapidly to lift the valve to the whole extent; to keep it fully open as long as possible, in order that the steam may be maintained at full pressure in the cylinder without any wire-drawing; and to let it fall and close as rapidly and as easily as it is opened. That the valve may be prevented from remaining open after having been released by the cam, the cam is formed on the under side with an inclined plane, by which the valve, if it lingers, is forced on to its seat in time to prevent any mischief. Such a contingency need never arise if the packing in the stuffing-box of the valve-spindle is kept in good condition, the weight of the valve being sufficient to cause it to close when in good order.

The framing foundation-plate, or bed-plate, is of cast iron, and consists of two parallel lines, one for each engine, tied by a transverse piece at half-length. The framing is of hollow section, of $1\frac{1}{2}$-inch metal, having two sides and a top, open below, 18 inches high, varying in width from 12 inches at the cylinders to 28 inches at the main shaft. Each engine-frame consists of two such hollow members, parallel, united by five transverse hollow ties. The extreme length of the frame, including the guide for the back piston-rod, is 58 feet 10 inches; or, excluding this, 48 feet $3\frac{1}{2}$ inches. It is cast in three pieces:—the main-shaft end, the cylinder end, and the back guide. The first piece is 7 feet $4\frac{1}{2}$ inches wide across the top; the second piece is $5\frac{1}{2}$ feet wide. These two pieces, the principal members, are fastened together with four $2\frac{1}{4}$-inch bolts and nuts, and four $2\frac{1}{2}$-inch bolts and nuts. The centre-lines of the two engines are 25 feet apart, and the centres of the cylinders are 3 feet above the base of the frames. The centre-line of the main-shaft is 20 feet from the middle points of the guide-bars, and these are 12 feet from the middle points of the cylinders.

The cylinders, figs. 725 and 726, are 42 inches in diameter, with a stroke of 7 feet. They are 2 inches thick, and the flanges are $2\frac{1}{4}$ inches thick. The cylinder-covers are hollow, of $1\frac{1}{4}$-inch metal, 11 inches and 12 inches deep, having six radial stiffening ribs and $2\frac{1}{4}$-inch flanges; each fastened to the cylinder with eighteen $1\frac{1}{4}$-inch bolts and nuts, at about $8\frac{1}{2}$ inches of pitch. The cylinder is sufficiently long to provide a direct clearance space of $\frac{3}{4}$ inch between the piston and the cover at the beginning of the stroke. The steam-ports, one at each end of the cylinder, are 18 inches by 6 inches, having an area of 108 square inches, about $1/13$th of that of the cylinder. The piston-rod is of steel, $6\frac{1}{2}$ inches in diameter, prolonged at $5\frac{1}{2}$ inches in diameter through the back cover of the cylinder. It is 27 feet long. The piston is of cast iron, hollow, of $1\frac{1}{2}$-inch metal, $8\frac{1}{2}$ inches thick. It has a single cast-iron packing-ring, 5 inches wide, $1\frac{1}{8}$ inches thick, cut at one place obliquely, and tongued with brass, expanded against the cylinder with twelve short C steel springs $3/16$ inch thick, of $7\frac{1}{2}$ inches span. These abut on a circular rib, forming part of the piston, which is
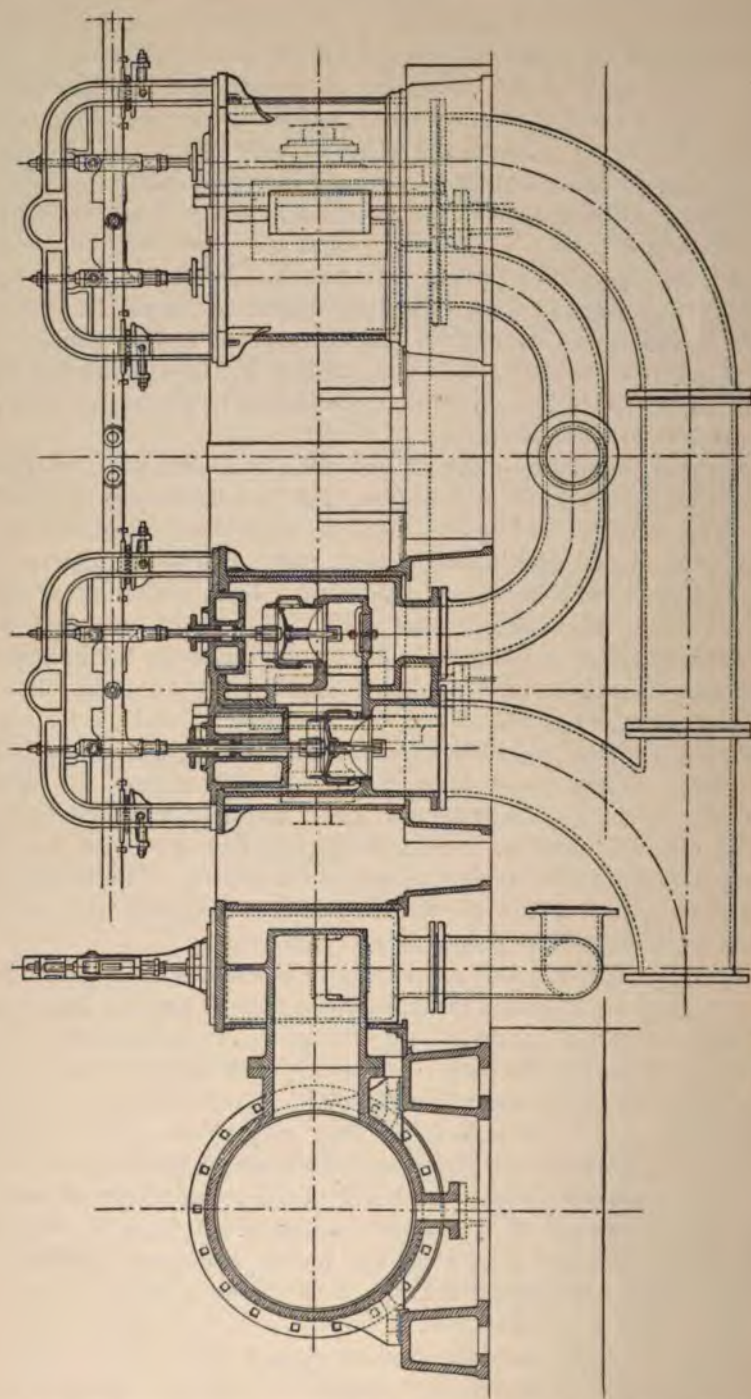
Figs. 725.—Daglish's Winding Engine: Cylinder and Valve-boxes; Vertical Sections. Scale 1/40th.

connected to the centre with eight radial ribs 1¼ inches thick. The

packing is kept in place by a junk-ring 2 inches thick, fastened with eight

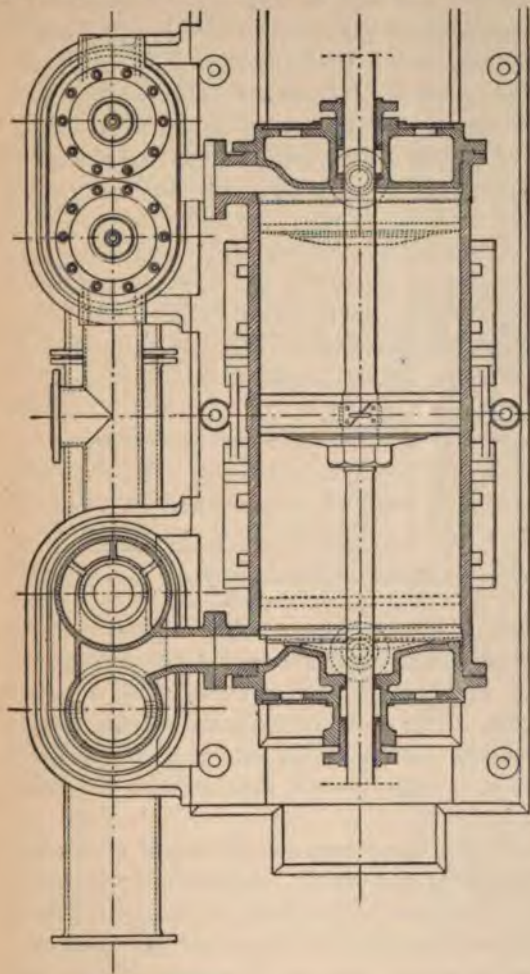1¼-inch bolts and brass nuts. The packing usually applied by the constructors consists of three cast-iron packing-rings, 1⅛ inches wide, ½ inch thick. The centre is 10½ inches deep, bored taper to 8 inches and 7 inches in diameter to receive the piston-rod, which is fastened by a wrought-iron nut 4½ inches thick, on a diameter of 6½ inches, screwed with a thread of ¼-inch pitch, secured by a set-pin.

From each end of the cylinder there is a 4-inch conduit-pipe, figs. 727, fitted with a 5-inch conical relief-valve of 12½ square inches effective area, with a lever and weight to allow of the escape of water which may accumulate in the cylinder. The four valves can at any time be lifted simultaneously by the engineman from his platform—a facility which is of special import-
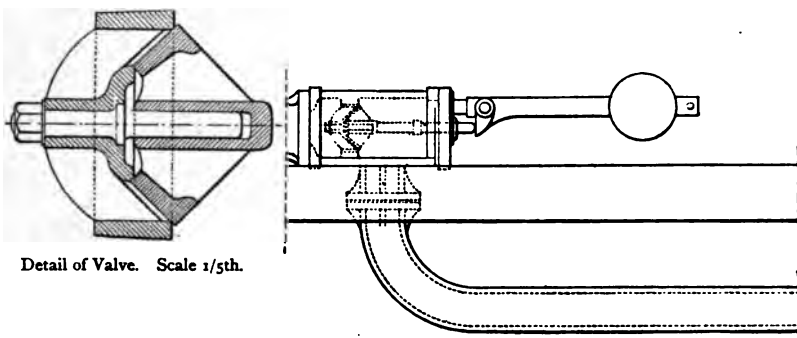
Fig. 726.—Daglish's Winding Engine: Cylinder and Valve-boxes; Horizontal Section. Scale 1/40th.

ance when the engine is started after having rested for some time.

The guide-bars are of cast iron, hollow, averaging 1½ inches in thickness, 10½ feet long between the centres of the bolts, two pairs to each cylinder, 4 feet 3 inches apart horizontally between centre-lines. The bearing surfaces are 9 inches wide. The lower bar is of 11½ inches uniform depth, of 1¼-inch metal, 1½ inches at the top, formed with a ledge at each side to contain oil. The upper bar is 12½ inches deep at the centre, reduced to 8½ inches at each end, of 1½-inch metal, 2 inches thick at the bottom or wearing side. They are fixed at each end with a 2½-inch turned bolt, screwed and nutted at the upper and lower ends.

The back guide-bar is formed similarly to the lower main guide-bar, with a like bearing surface.

The crosshead is of wrought iron, consisting of a central block 18 inches

long, 10½ inches square, turned down to 10¼ inches at each end, with two journals 7 inches by 7 inches, one at each side, to take the connecting-rod which is forked; and lateral extensions, to take the guide-blocks, 9 inches long, and taper from 4½ inches to 4 inches in diameter. The blocks are secured in place with a 3-inch nut on each end of the crosshead. The total length of the crosshead between the nuts is 5 feet. The centre, 18 inches long, is bored to receive the end of the piston-rod, which is reduced to 6¼ inches in diameter and tapered to 5¼ inches, and fastened with a

Detail of Valve. Scale 1/5th.

Figs. 727.—Daglish's Winding Engine: Conduit-pipe and Relief-valve from end of Cylinder. Scale 1/24th.

5-inch nut 6 inches thick, secured by a split cotter. The slides are of cast iron, 2 feet 4 inches long, each with a wearing piece adjustable with a steel wedge tapered ½ inch in 27½ inches of length, and set with a 1-inch screw at one end with double-nuts. The outer or back end of the piston-rod is reduced to a diameter of 5¼ inches, to fit into a cast-iron slide-block 25 inches long, into which it is cottered. It is fitted with a wearing piece and adjusting steel wedge.

The connecting-rod of each engine is of hammered forged scrap iron, 20 feet long, or 5.71 times the length of the crank. It is round, 7 inches in diameter at the crosshead end, 7½ inches at the crank end, 9¼ inches at the mid-length. It is forked for two bearings at the crosshead, 7 inches in diameter, 7 inches long, 10½ inches apart, with round brasses. Each pair of brasses is held by a strap fastened with two steel gibs and a cotter, 1⅛ inches thick, the cotter being secured by a screwed bolt formed on one of the gibs, with double-nuts. The crank end is solid forged, and has a bearing 9 inches in diameter, 12 inches long. The brasses are fastened with a gib and cotter, 1¾ inches thick. A bearing piece of steel is applied to the back of the brasses, against which the cotter is driven; and the cotter is secured by a screwed bolt on the gib, with double-nuts.

The main shaft is of hammered scrap iron, 20 inches in diameter for a length of 9 feet 10 inches in the middle, as forged; turned to 22 inches to receive the bearings of the drum; with journals 18 inches in diameter, 30 inches long, and outer ends to receive the cranks, 20 inches in diameter, 18¼ inches long. The centres of the journals are 18 feet 4 inches apart; and the total load on the journals is 75 tons, in addition to which there is

the weight of the rope, about 5½ tons. The centres of the engines are 25 feet apart, and the total length of the shaft is 24 feet ½ inch. The cranks, two in number, are of wrought iron. They have a radius of 3½ feet. The central eye is 36 inches in diameter, 18 inches deep, bored out to 20 inches in diameter, leaving 8 inches of metal round the eye. The eye for the crank-pin is 12 inches deep, bored taper from 9½ inches to 9 inches, and is 22 inches in diameter, making 6⅜ inches of metal round the eye. The web is 9 inches thick, and has a minimum width of 21 inches at the smaller end. The crank-pin is 9 inches in diameter, 12 inches long for the journal, with a collar pinned on the outer end to keep the connecting-rod. It is turned to fit the eye of the crank, which is shrunk on it. The pin is driven into the eye with a tup, and is fastened with a nut 4 inches thick. It is also fastened with a key 2¼ inches by 1 inch thick. The cranks are shrunk on the shaft, and fastened each with a key 5 inches by 2 inches thick.

Each cylinder is fitted with a valve-box at each end: each valve-box containing two gun-metal equilibrium valves, one for admission of steam to the cylinder, the other for exhausting the steam; 11 inches and 12 inches in diameter inside respectively, having 95 square inches and 113 square inches of area, or $1/14.6$ part and $1/12.2$ part of the area of the cylinder. The lower valve-seats are knife-edges, of these diameters respectively. The upper valve-seats are conical, offering an equivalent horizontal width of bearing of $3/16$ inch, and making the effective diameters of the upper seats $(3/16 \times 2 =) $ ⅜ inch less than those of the lower seats—differences which are just sufficient to keep the valves closed steam-tight.
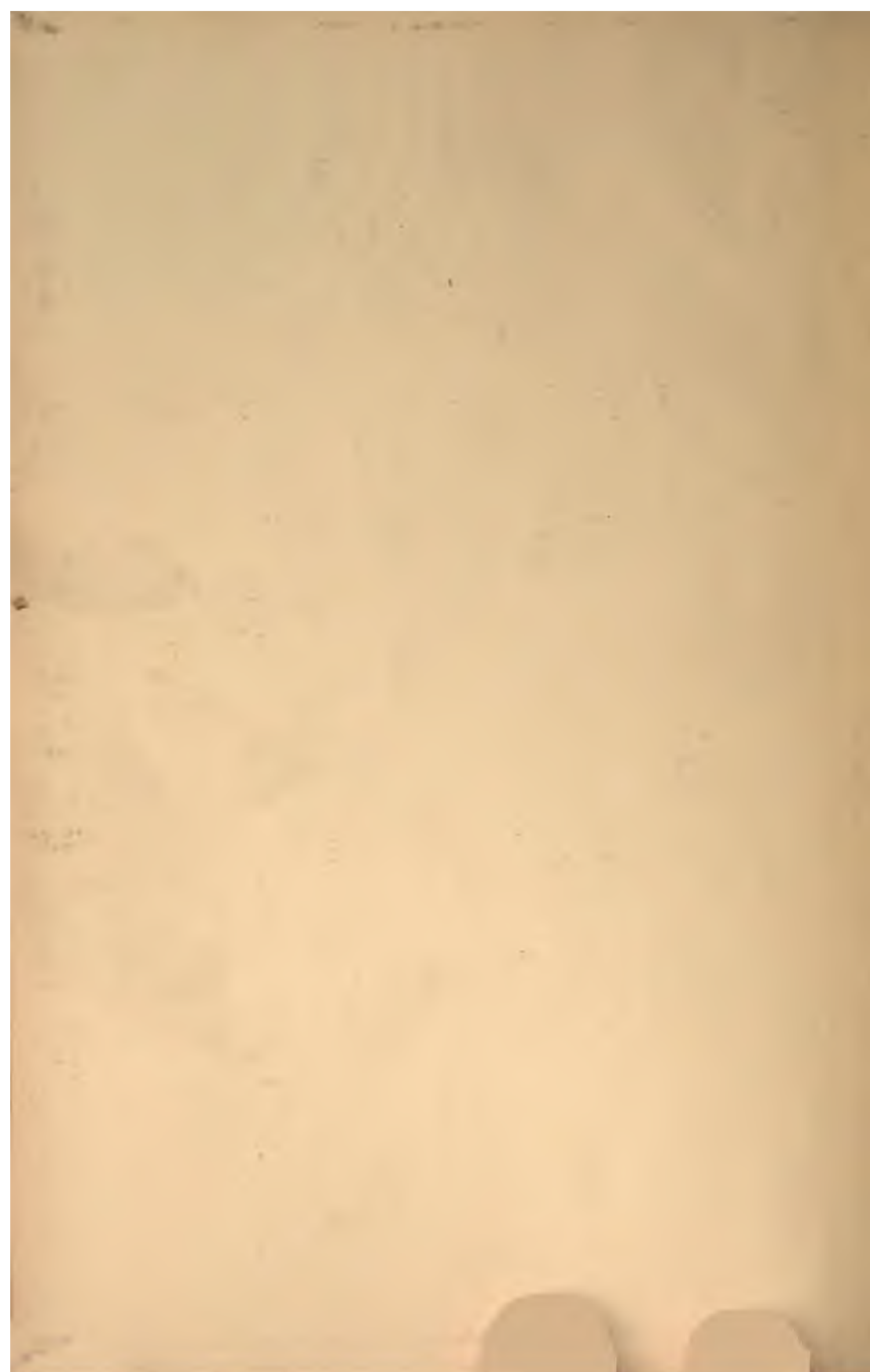
The cam-gear has already been explained. The lift of the valves, by the cams, is for the steam-valves 2¼ inches, for the exhaust-valves 2½ inches. The valves are of ½-inch gun-metal, with 1¼-inch steel spindles. The valve-boxes are of 1-inch cast iron; the steam-pipes are 11 inches in diameter, of 1⅛-inch metal; the exhaust-pipes are 18 inches in diameter, of ⅞-inch metal, and are made so unusually large for the purpose of reducing the back-pressure to a minimum. The steam stop-valve is placed at the branching of the main steam-pipe to the two cylinders. It is placed at a low level, to clear the floor-line. It is an equilibrium-valve, similar to the steam and exhaust valves, 15 inches in diameter, in a cast-iron box 24 inches in diameter. It is balanced by a counterweight, and is regulated by connections from the foot-plate. The main steam-pipe is 18 inches in diameter.

Each cam-bar is 1¼ inches thick, 4 inches deep. It reciprocates horizontally on two groups of six live steel rollers, $1^1/16$ inches in diameter, which roll between two steel plates, the lower of which is adjustable for wear. The motion is derived from the ordinary expansion-link motion through an upright rocking-lever, 4 feet 9¾ inches long, pivoted at its lower end, linked to the cam-bar at its upper end. The expansion-link is of the stationary type, 33½ inches long between the end centres, 3½ inches thick, with a slot 3½ inches wide, to receive the die. It is fitted with

suspending bars, one at each side, formed with 1½-inch pivots, at mid-length, by which the link is supported, and which carry slides which reciprocate in a pair of guides fixed to the sole-plate. The eccentrics are 2 feet 9½ inches in diameter, with a throw of 8 inches; they are 3⅜ inches wide, having a central fin on the periphery; applied in two parts, fastened together with two 1-inch square bolts, cotters and double-nuts; fixed on the shaft with two set-screws. The eccentric-straps are of cast iron, 3 inches wide, strongly ribbed on the periphery, joined with two 1¼-inch bolts and double-nuts. The eccentric-rods are 14½ feet long between centres, and are pinned to the expansion-link at 20-inch centres. The radius-link is 8 feet long, and is pinned to the rocking-lever at a distance of 38¾ inches from the fulcrum, or two-thirds of the whole length of the lever. The travel of the cam-bar is therefore 1½ times the traverse of the link-block.

The winding-drum, figs. 2, 4, 5, and 6, Plate XIV., is of the double-conical type, designed, like the fusee of a watch, to provide a uniform or nearly uniform stress on the engine,—compensating by its varying radius for the varying weight of rope in the pit. It has a maximum diameter of 33 feet and a minimum diameter of 18 feet; 12 feet wide between the summits of the cones, 5 feet wide between the bases of the cones, and 13 feet 2 inches wide over all. The drum is constructed upon two cast-iron discs, 8 feet in diameter, of which the eyes are 18½ inches wide, bored to 22 inches in diameter to fit the shaft, and each of them bound with two hoops of 3-inch square iron. The skeleton of the drum consists of 32 radial frames, alternately constructed of T-steel 6 inches by 6 inches by ½ inch thick; and T-steel 5 inches by 4 inches by ½ inch thick; known respectively as main frames and secondary frames. These are riveted to two circular steel plates, 18 feet in diameter, which form the lateral summits of the cones, and the frames and plates are fastened with turned bolts and nuts to the central cast-iron discs. The conical outlines are not straight, but are slightly hollow in longitudinal section, according to a special curve so designed as to give a uniform pitch of the spiral grooves, and at the same time to secure lateral clearance for the rope, in order that when the rope is being either coiled or uncoiled, at any part, it shall not approach within ⅜ inch of the groove next above it. The grooves are of steel, of a peculiar section, figs. 5 and 6, Plate XIV., of ½-inch metal at the sides, ⅝ inch thick at the bottom, to receive the 6-inch steel wire-ropes, which are about 1⅞ inches in diameter. The spiral grooved coil is riveted to the frames. Distance-pieces, of cast steel, are closely fitted between the coils, and riveted to the frames: relieving the rivets of much of the stress. The steel employed in the construction of the drum is made of Siemens-Martin steel, manufactured by the Steel Company of Scotland. It has a tensile strength of 33 tons per square inch. The cylindrical rim of the drum is formed with two inner T-steels and two outer angle-steels, 6 inches by 4 inches, by ½ inch thick, and is covered with 3-inch beech-wood. The section between the two T-steels, 12 inches apart, is used as the break-ring. The smaller cylindrical portions of the drum are also covered with beech-wood, on which spare rope is bedded.